PEDAGOGY FOR LEARNING FROM FAILURE USING CDIO FRAMEWORK: MARINE ENGINEERING PILOT RUN

Sin-Moh CHEAH

Department of Educational Development, Singapore Polytechnic

David TAY, Hong-Lin LIEW

Singapore Maritime Academy, Singapore Polytechnic

ABSTRACT

This paper described how the pedagogy of learning from deliberate failure based on the CDIO Framework was adopted and implemented in a marine engineering course in Singapore Polytechnic. More specifically, the paper shares the results of a study whereby a set of integrated learning experiences were introduced into a 60-hour Year 2 core module entitled "Marine Engine Room Simulator Training" taken by 4 classes with a total of 59 students, over a semester. Two classes served as the experimental groups, where they received instructions from the facilitators about skills in visualization and solved additional "challenge" questions that were inserted in the learning tasks to get them to identify potential failure scenarios and consequences of selected failures. The other 2 classes function as control groups, where students learned the module in the 'traditional' way, i.e. without any emphasis on learning from failures. The aim is to firstly "prepare the minds", that is to change and shape students' attitudes toward failure in a series of learning tasks based on a marine engine simulator for the first 8 weeks before the semester break. Students learn about the engine systems of a ship, which include the generator, compressor, seawater and freshwater cooling, pump and ballast, etc. This is followed by another 7 weeks after the semester break of simulator-based training. Here the students are required to make use of the first 8 weeks' prior learning to work through various exercises simulating shipboard operation of preparing the engines for departing port, watch keeping at sea, and arriving port. Learning experiences from the 2 groups of students are compared, firstly via a pre-test post-test survey administered at the beginning and end of the semester. 2 questionnaires are used: the School Failure Tolerance Scale and the Kirton Adaptor-Innovator Inventory. Each student is also required to submit a reflection journal, to enable comparison of attitudes toward failure between the 2 groups. Lastly, a quick comparison of the students' assessment marks is also shared. The results showed that the failure tolerance of students from experimental group had decreased, contrary to expectations, although statistically the difference is not significant. This outcome, plus the input from reflection journals and assessment scores yield insights other factors that can affect students' engagement in the learning tasks and suggested that more needs to be done to improve the students learning experience in learning from deliberate failure.

KEYWORDS

Deliberate Failure, Marine Engineering, CDIO Core Standards 1, 2, 3, 6, 7, 11, 12

INTRODUCTION

At the 2023 International CDIO Conference, Cheah (2023) introduced a pedagogy for learning from deliberate failure formulated using the CDIO Framework. "Deliberate Failure" in this context means that educators deliberately designed learning activities with elements/difficulties that will lead to students encountering challenges to complete the prescribed task, i.e. "failure". It thus builds on the insights that (i) failure constitutes powerful potential learning moments; (ii) but this often happens implicitly which limits the learning potential; (iii) it can thus be introduced into the curriculum more deliberately so that students are exposed to learning from failure in a safe environment.

About Learning from Failure

Literature reviews by Cheah & Thijs (2023) showed that there are 2 major desired outcomes from engaging in tasks designed to make students learn from failure:

(a) Promote innovation – this is by far the most common use of learning from failure, in areas of product design where one iterates from one prototype of another. This is usually associated with creativity and creative thinking in problem-solving. This type provides a context where there are no set guidelines students need to follow since the solution to specific design questions is not yet known.

(b) Ensure safe operation – this is the main learning outcome for courses intended to prepare graduates to work in "high-risk" industries involving complex systems such as nuclear power plant, chemical processing, and aerospace. Failure in any of the processes is to be avoided at all costs so as to ensure a safe and reliable operation. This provides a context where students have to deal with standard operating procedures; and learning from failure here serves as a reminder that such failures are to be avoided at all costs.

The various reasons for failure in Case (a) may involve students missing out on key insights from a user empathy study when conceiving potential solutions; or using the wrong assumption in the design of a device, or wrong choice of materials; underestimating the resources needed for a key task; or the whole cornucopia of factors during the process of conceiving, designing, implementing, and operating a product, process, system or service. Failure can be introduced deliberately to stress-test one's product or actively try to disconfirm existing assumptions which, in turn, may lead to a more innovative design. On the other hand, Case (b) may involve students unable to resolve a simulated operational problem in a chemical processing plant, for example, in identifying the underlying causes of the problem because the student is unable to discern the plausible cause-effect relationship among a plethora of process alarms (temperatures, pressures, flow rates, etc); and hence failed in taking the proper corrective actions to return the processing plant to its stable operating conditions. The negative consequences can deteriorate very quickly in such time-sensitive events. For training, failure can be introduced deliberately here as the classroom can provide a safe space for students to experience failures without the potentially catastrophic consequences.

Learning from Failure: Improving Safety in Complex Systems

In a nutshell, the pedagogy proposed by Cheah (2023) is aimed at addressing the challenges posed by Case (b) above. The pedagogy firstly outlines the general principles for integrated curriculum redesign using CDIO, that progressively shapes students' attitudes toward failure, from "one of fearsome to one of welcome": developing skills and attitudes such as critical thinking, systems thinking, resilience and perseverance. A series of integrated learning experiences can then be designed based on increasing levels of difficulty to develop these skills and attitudes. An example of how such as the approach can be used as roadmap for curriculum redesign was illustrated using chemical engineering as an example. The aim is to better prepare students to work in industries typically classified as those made up of complex systems (Cook, 1998, 1999, 2020), of which chemical plant operation is one example. Some key characteristics of complex systems include: (i) they contain changing mixtures of failures latent within them; (ii) they always run in degraded mode; (iii) changes to the system can introduce new forms of failure; (iv) safety is a characteristics of systems and not of their components; (v) views of 'cause' limit the effectiveness of defenses against future events, and (vi) failure-free operations require experience with failure.

About the Singapore Maritime Academy, Diploma in Marine Engineering and the module Marine Engine Room Simulator Training

The Singapore Maritime Academy (SMA) is one of 10 academic schools in Singapore Polytechnic (SP). It offers specialized programs for the maritime sector, including the Diploma in Marine Engineering (DMR). This program focuses on the operation and maintenance of ship engines and machinery, aligned with the International Maritime Organization's (IMO) Standards of Training, Certification and Watchkeeping (STCW) Code Table A-III/1 (see Appendix 3), which is commonly referred to as IMO Certificate of Competency (CoC) standards. After attainment of the required competencies, DMR students at SMA will be awarded the Class 5 Certificate of Competency. Graduates often start as junior engineer officers in shipping and ship management firms, advancing their careers and competency levels over time.

The module selected for this study on impact of learning from failure is a 60-hour Year 2 core module entitled "Marine Engine Room Simulator Training" taken by a total of 59 students allocated into 4 classes. The module was delivered within 1 semester, i.e. 15 weeks of study. The semester is made up of 2 terms: 8-weeks of Term 1 and 7-weeks of Term 2; with a 3-week term break in-between.

The module learning outcomes are as follows:

1. Know the propulsion plant arrangement, instrumentation & control systems and operational procedures.
2. Apply safe operational procedures to prepare various systems (sea water and freshwater cooling, compressed air, fuel oil, lube oil)
3. Apply safe operational procedures to prepare and start auxiliary machinery.
4. Apply safe operational procedures to prepare main propulsion engine for starting.
5. Apply knowledge, understanding and proficiency to monitor the engine performance.
6. Apply knowledge, understanding and proficiency to detect the faults in the machinery system and take immediate remedial action for safe operation of the plant.
7. Apply knowledge, understanding and proficiency to maintain safe engineering watch.
8. Apply correct procedures to response promptly to various engine room emergency situations.

CONTEXT FOR STUDENT ENGAGEMENT

Figure A1 in Appendix 1 shows the engineering learning workspaces for the module. The engine room simulator complex consists of the full-size engine room in which the machinery is laid out in 3 platforms, and a set of Power Plant Trainer (PPT) Workstations in a control room that simulates the operation of the engine room, which is based on the behaviour of main propulsion and the associated auxiliary machinery of a large crude oil tanker of 180,000 dwt.

The mean draft of this vessel is 18 metres, and the maximum operational speed is about 15 knots. In the physical plant, the various machinery, pipelines and fittings are not thermodynamically or mechanically loaded. Students can walk around the plant and identify the different components and learn how they are connected to one another. The plant components are fitted with sensors, switches, gauges and other instruments that allows students to interact with the engine via local panels on the platform, and workstations consoles in the control room.

Students in the DMR program are required to demonstrate evidence of competency in the following areas specified in the IMO CoC (i.e. STCW Code Table A-III/1):

1. Maintain a safe engineering watch.
2. Use the English language in written or oral form.
3. Use communication systems.
4. Operate main and auxiliary machinery and associated control systems.
5. Operate fuel, lubrication, ballast and other pumping systems and associated control systems.
6. Operate electrical, electronic and control systems.
7. Maintenance and repair of electrical and electronic equipment.
8. Appropriate use of hand tools, machine tools and measuring instruments for fabrication and repairs on board.
9. Maintenance and repair of shipboard machinery and equipment.
10. Ensure compliance with pollution-prevention requirement.
11. Maintain the seaworthiness of ship.
12. Prevent, control and fight fires on board.
13. Operate lifesaving appliances.
14. Apply medical first aid on board ship.
15. Monitor compliance with legislative requirements.
16. Application of leadership and teamworking skills.

Essentially, the learning of the above areas is conducted as follows: Term 1 was used for "*Preparing the Mind for Learning from Failure"* whereby students first familiarize themselves with the engine room and PPT operation; and able to prepare all the different components (seawater and freshwater cooling systems, compressed air system, lube oil and fuel oil systems) to prepare the ship from cold start-up all the way to main power start-up to sail out from the harbour. Term 2 is then used for "*Applying Lessons Learnt from Failure in Operation"* whereby students apply what they had learnt in Term 1 to get the generator started up and ready the ship. They will work through various exercises simulating shipboard operation of preparing the engines for departing port, watch keeping at sea, and arriving port.

Application of the CDIO Framework in Brief

This follows the 'typical' CDIO approach of addressing the following 3 key questions:

1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs, and at what level of proficiency?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

Cheah (2023) had shared how the relevant CDIO standards can be used to guide the design of curriculum featuring Assessment learning from failure. The needs and context for learning are pretty much defined by the requirements of the Certificate of Competency standards from the International Maritime Organization (IMO). In CDIO, we are interested in learning outcomes related to skills and attitudes needed in the achievement of the desired technical outcomes. In this work, the learning outcomes are similar to that articulated by Cheah (2023) in terms of getting students to understand the relationships between process variables (flow, temperature, pressure, level) in the operation of the ship engine. Figure 1 shows a simplified relationship between selected CDIO core standards used in guiding the design of learning tasks.

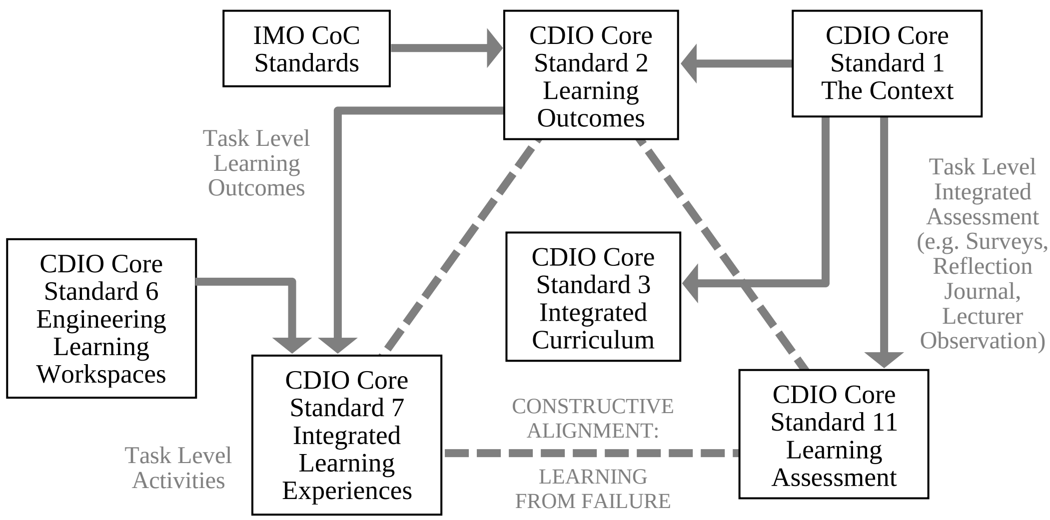

Figure 1. Application of Selected CDIO Standards in Designing Learning from Failure

INTEGRATED LEARNING EXPERIENCES TO PROMOTE LEARNING FROM FAILURE

The learning progression for the module “Marine Engine Room Simulator Training” over the semester is shown in Appendix 2, Figure A2. A key feature of the training is that students get to repeat what they learned from the previous week’s lessons in the present week as made progress in weekly learning in gradually readying the ship to set sail. This lends itself readily for the introduction of interventions for learning from deliberate failure.

Of the 4 classes that took this module, 2 classes (2A/21 and 2A/24) served as the experimental group, where they received instructions from the Facilitators about skills in visualization and solved additional “challenge” questions that were inserted in the learning tasks to get them to identify potential failure scenarios and consequences of selected failures. The other 2 classes (2A/22 and 2A/23) function as the control group, where students learned the module in the ‘traditional’ way, i.e. without any emphasis on learning from failures. In the control group, the lecturers walk the students through the entire process, telling them what to do at each stage; and also observe students replicating the process. The whole learning is very procedural in nature, aimed at students being able to successfully complete each task as required in the manual. Even when students made mistakes and alarms sounded, they were briefed on the nature of such alarms and guided in the corrective actions to take. In contrast, for the experimental group, students were still guided but more prompting and questioning. The experimental group also has the additional challenges designed into the learning tasks that include deliberate failure in some of the tasks they had successfully completed in earlier sessions. Marks for the completion of the tasks are not affected by the inclusion of learning from failures for the experimental group, as the challenge questions posed are formative in nature.

Since students work in groups of 4-5 members, we also took advantage of introducing peer learning in selected tasks, whereby different groups of students encountered different types of failures (see summary in Tables 1 and 2, and examples given below). Hence, they will have to teach one another in order to gain a more complete understanding of how different failures may occur. In this manner, collectively everyone will gain more from the exercises.

Term 1: Preparing the Mind for Learning from Failure

Table 1 shows the "interventions" implemented at selected learning points for Term 1. The activities were designed using the approach suggested by Cheah (2023). It is meant to address the first part of the learning from failure pedagogy: that is to prepare the students' mind towards learning from failure namely through visualization of the processes involved, and anticipating in advance plausible failure, and potential consequences of a failure. They are reminded that such learning went forgetting certain operating procedures. The activities also attempted to develop students' abilities to analyze relationships among key process variables for the ship engine, power and auxiliary systems as displayed in the performance dashboard. This will address the challenge of "unknown known" among students – they don't know what they had learnt earlier, as they are not able to make connections between lessons learnt; crucial in the analysis of causes of failure (Cheah, 2023).

Example 1: Failure during Main Power Start-Up

2 groups of students will be given Challenge Case A, while another 2 groups will be given Challenge Case B, as explained below. In both cases, students need to analyze and understand the relationship between process variables to make sense of the changes reported in the system dashboard.

- Challenge Case A: Sea chest blocked with plastic or other garbage; or strainer plugged with varying degree of dirt.
- Challenge Case B: LT Fresh Water Pump with varying degrees of low suction pressure, which could be due to pump wear.

Example 2: Failure during Auxiliary System Start-Up (1)

This activity is again to expose students to the relationship between process variables in another important item in the ship's engine. Facilitator will load exercise with any of the following issues causing high compressed air temperature.

- Varying degrees of low LT Fresh Water Pump pressure, where potential causes could be air leak on the suction side or pump problem.
- Varying degrees of dirty compressor intercoolers, and its impact on system performance in terms of affected process variables (namely temperature and pressure), from which students will infer the "health status of the system.

Example 3: Failure during Auxiliary System Start-Up (2)

Facilitator loads exercise with possible conditions of dirty coolers, filters on fuel, lube oil, air and water. Students need to identify the cause and take appropriate action before "BROWN OUT" or "BLACK OUT" occurs. (The term BROWN OUT refers to a situation where some of the machinery stops functioning due to temporary loss of electrical power, while BLACK OUT refers to total loss of electrical supply which triggers a complete shutdown of the ship's propulsion plant which can be detrimental to the ship's safety should the ship be in congested waters or arriving or leaving port). This is where students need to understand the relationship between the various process variables to ascertain the source of failure(s).

Table 1. Lesson Plan for Term 1 Activities where Interventions were introduced

<table>
<tr><th colspan="3">Term 1 - Familiarization</th></tr>
<tr><th>Week No.</th><th>Brief Description of Activity</th><th>Intervention to promote learning from failure</th></tr>
<tr><td>1</td><td>Cold Ship Start-Up (1)
Familiarization with Engine Room and Power Plant Trainer</td><td rowspan="3">A survey was administered to ALL students on their attitudes toward failure.
In the initial familiarization in Week 1, and subsequent learning in Week 2; students learnt to start the emergency generator whereby conditions for start-up (e.g. battery, fuel oil, lube oil and cooling water level) were all met. In Week 3, some of these conditions were deliberately engineered to be at failed state. Students learnt to visualize the start-up process on the sequence of tasks to be completed, and potential failures in the task that can affect successful startup of the emergency generator with a given time frame.</td></tr>
<tr><td>2</td><td>Cold Ship Start-Up (2) Seawater Cooling Systems Fresh Water Cooling Systems</td></tr>
<tr><td>3</td><td>Cold Ship Start-Up (3)
Compressed Air System</td></tr>
<tr><td>4</td><td>Main Power Start-Up
Diesel Generator Start-Up and Paralleling</td><td>In performing this task, students will encounter challenges in prior tasks such as seeing an alarm in the seawater or freshwater system (week 2); and failure to undertake the proper corrective action can result in a shutdown of the system.</td></tr>
<tr><td>5</td><td>Auxiliary System Start-Up
Fuel Oil System Lube Oil System</td><td>In performing this task, students will encounter challenges in prior tasks such as seeing an alarm in the compressed air system (week 3); and failure to undertake the proper corrective action can result in a shutdown of the system.</td></tr>
<tr><td>6</td><td>Auxiliary Boiler Start-Up
Steam Generation</td><td>In performing this task, students will again make use of prior learning to identify from the information shown in the dashboard, the plausible cause of failure from a range of possibilities.</td></tr>
<tr><td>7</td><td colspan="2">Continual Assessment 1 (INDIVIDUAL, 1-hr, 40%): Learning Journal
All students (control and experimental groups) submit a report comprising answers to questions posed in each activity for the past 6 weeks. The experimental group is not required to include the answers to the challenge questions.
Reflection by Experimental Group only</td></tr>
<tr><td>8</td><td colspan="2">Mid-semester Test Week – No lesson for this module</td></tr>
<tr><td>9-11</td><td colspan="2">Term Break (3 weeks)</td></tr>
</table>

Reflection: Learning Experience

Students from the experimental group are required to submit an individual reflection journal on their learning experience, and answer the following questions based on Gibbs' Reflective Cycle:

- Description of the Experience: What happened?
- Feelings and Thoughts about the Experience: What were you thinking and feeling?
- Evaluation of the Experience: What was good or bad about it?
- Analysis to Make Sense of the Situation: Why was it good or bad?
- Conclusion about the Situation: What you learnt and what you could have done differently?
- Action Plan: What will you do differently?

Term 2: Applying Lessons Learnt (in Term 1) from Failure in Operation

Table 2 shows the activities students will undertake in Term 2, continuing to build on the learning gained in Term 1. For this paper, we are interested in students learning from failures up to the point when they ready the ship to depart from port and set sail. Their learning will be put to test in Continual Assessments 2 and 3, which are further elaborated below.

For Term 2 activities, similar failures as introduced in Example 1 in Term 1 can again be introduced, but with more variation to see if students are able to identify other causes in addition to what they had learnt earlier. For instance, in a variation of Case A, the sea chest is now blocked with ice; which necessitates different corrective action: instead of using compressed air to flush the section, steam should be used to melt the ice! For Case B, the deterioration of LT Fresh Water Pump performance could be due to reduction in pump speed.

Table 2. Lesson Plan for Term 2 Activities where Interventions were introduced

Term 2 - Operation		
Week No.	Brief Description of Activity	Intervention to promote learning from failure
12	*Revision of Term 1* Start of Parallel Generator – *after going through the steps in Term 1*	Facilitator gave a quick recap of lessons learnt from challenge questions in Term 1. Students are asked to reflect on the failure(s) encountered during the start-up process.
13	Continual Assessment 2 (INDIVIDUAL, 1-hr, 30%): “Cold Ship Start Up to Own Power” Each student is to demonstrate his/her understanding from all earlier lessons. Reflection by Experimental Group only	
14	“One Hour Notice” Preparation to leave port and set sail *Lube Oil Purifier Start up*	In performing this task, students will encounter challenges in starting up the Lube Oil Purifier and failure to undertake the proper corrective action can result in loss of main engine lube oil.
15	Repeat of “One Hour Notice” Leaves port and set sail	“Full away procedures”, No intervention planned
16	Out at Sea: Keeping watch duties and responding to alarms	Facilitator simulates various alarm conditions for practice
17	Continual Assessment 3 (INDIVIDUAL, 1-hr, 30%): “One Hour Notice to Departure” and set sail. Each student is to demonstrate his/her understanding from all earlier lessons.	
18	Set Aside for Make-Up Lessons, if needed	
19-20	Semestral Examination (2 weeks) – Not Applicable for this Module	

Example 4: Failure to bring up Parallel Generator

For the first activity in Term 2, failure to start the parallel generator mostly stemmed from failure to carry the process in the prescribed manner. What was done differently between the experimental and control groups was that students from the experimental group were asked to reflect on what they did wrong, and why the following the steps mattered. On the other hand, students from the control group were told what went wrong and had the steps explained to them by the Facilitator.

Continual Assessment 2 (30%): Cold ship Start up to Own Power

This is a summative assessment, administered individually. Students essentially has to demonstrate competency in getting the ship to operate on Main Power by going through all the steps from cold start (Week 1, Term 1 in Table 1) to starting the first main Generator (Week 4, Term 1 in Table 1). The experimental group was required to submit a reflection journal using the same Gibb's Reflection Cycle form used in Term 1.

Example 5: Failure to successfully operate the Lube Oil Purifier

In the next activity, after successfully started the parallel generator, students will also need to bring into operation the lube oil purifier. Facilitator will take note of how many students still made mistakes in this key step. Facilitator will also demonstrate an example of failure to emphasize that even when all start-up procedures were adhered to correctly. Facilitator will explain the cause and effect to students from the control group, For the experiment group, the cause of the introduced failure will not be made known to students. Students will be asked to provide plausible reasons that can lead to a failure, and potential consequences of each failure. Facilitator can also different failure scenarios for different experimental groups, again to promote peer learning). This will set the context for Continual Assessment 3.

Continual Assessment 3 (30%): Preparing to Sail out of Port

This is a summative assessment, administered individually. Students essentially have to demonstrate competency in getting the ship ready to leave port, by going through all the steps from cold start (Week 5, Term 1 in Table 1) to starting the parallel generator (Week 15, Term 2 in Table 2) as well as the various systems required to operate the main propulsion plant. Although both groups (experimental and control) will go through the same assessments, Part 1 of the assessment (out of a total of 4 parts) is of interest for this work as the question here pertains to how they problem-solve the challenges posed, and we wished to see if there are differences in answers from students from the 2 groups.

FINDINGS FROM STUDENTS ON THEIR LEARNING EXPERIENCES

2 surveys were carried out for all students (both experimental and control groups) in order to find out their learning experience: a pre-test survey at the beginning of Term 1 (i.e. start of semester) and a post-test survey in Term 2 (i.e. end-of-semester). For each survey, 2 sets of questionnaires are used – the School Failure Tolerance Scale (SFTS) (Clifford, 1988) and the Kirton Adaptor- Innovator (KAI) Inventory (Kirton, 1976). We also compared both groups of students' assessed work, namely the continual assessments as noted in Table 1 and Table 2. In addition, the experimental group is also required to submit a reflection journal for their learning.

Due to time constraint, we did not manage to conduct focus group discussions with the students.

Results from Students Surveys: Pre-Test and Post-Test

First, we share the survey findings from the 2 groups of students. A total of 44 students responded, comprising 26 students from the experimental group (100% responses) and 18 from the control group (where 18 out of 33 responded, a rate of 54.5%). The average SFTS score, and KAI score are shown in Table 3.

Table 3. Failure Tolerance and KAI scores of Students: Pre-Test vs Post-test

Group	Average SFTS Score			Average KAI Inventory Score		
	Pre-Test (Start of Semester)	Post-Test (End of Semester)	p-value	Pre-Test (Start of Semester)	Post-Test (End of Semester)	p-value
Total	2.961	3.039	0.1610	2.900	2.870	0.4896
Experimental	3.020	3.000	0.7950	2.865	2.910	0.2959
Control	2.875	3.095	0.0051	2.952	2.812	0.1112

Focusing on the average SFTS Scores in Table 3, we can see that the results were the exact opposite of what we expected, i.e. there is an increase in failure tolerance for the control group instead of the experimental group, even though they are not statistically significant. This is partly due to the small sample sizes for both groups. We can say that the two groups of students have similar failure tolerance levels. The counter-intuitive results would appear to suggest that students from the experimental group had become less “failure-tolerant” as a result of the various interventions introduced. One way to interpret this is that students from the experimental group, having been exposed to a different way of carrying out the simulated tasks – one with more probing from lecturers and a good dose of additional challenges questions – felt more intimidated or less confident when they realized that some scenarios are more complicated than they anticipated, beyond just follow the operating procedures. On the other hand, the students from the control group may have grown accustomed to the procedures as they were guided every step of the way by the lecturers, and they their confidence grew, resulting in higher “failure-tolerance”.

Turning to the KAI Inventory Score, likewise statistically the difference between the experimental group and the control group score for KAI inventory is also not big enough to be significant. Curiously, the results for the KAI Inventory Score were reversed for the experimental vs control groups. This seemed to suggest that students from the experimental group developed more propensity to think differently as a result of being exposed to more challenging questions.

Besides that, we can also speculate that all students had not been exposed to any prior briefings on learning from failure; especially for the experimental group. They were not explicitly informed of any possible encounter beyond what they read in the laboratory manual. It can be hypothesized that they carried the same mindset as that from Year 1 – that is, “learning” means the lecturers will show them what needs to be done and. Therefore, the additional challenge may come as an unpleasant surprise to them. This can be seen in the reflection questions from the students from the experimental groups, which we elaborated more in later section.
The results suggested to us that we need to beyond average values, and to look at findings of

student scores for their assessments at the class-level as well. This is discussed in the next section. Due to time constraint, we did not manage to reanalyze the SFTS and KAI Inventory Scores any deeper into the class or student levels.

Analysis of Students Assessment Results

Table 4 shows the comparison of results for both the experimental group and control group for their graded assessments, all administered individually. The acronyms used are shown in the bottom of the table.

Table 4. Comparison of Results from Graded Assessment

Group	Students Background	LAS score	CA1 Mean	CA1 Std Dev	CA2 Mean	CA2 Std Dev	CA3 Part 1 Mean	CA3 Part 1 Std Dev
Experimental Group 2A/21	N- & O-levels	7-25	69	14.59	73	15.89	51	11.73
Experimental Group 2A/24	ITE & some O-levels	17-20	71	12.16	79	14.42	52	3.75
Control Group 2A/22	O-levels & some ITE	9-25	74	8.11	80	11.58	53	9.19
Control Group 2A/23	ITE & some O-levels	19	76	4.68	71	22.76	52	15.87
CA: Continuous Assessment, LAS: Last Aggregate Score – a figure derived from a student's polytechnic entry requirements based on his/her secondary school results (O- or N-levels) and serve as indicator of students' academic ability (the lower the score, the better), ITE: Institute of Technical Education – vocational training for students who were not initially eligible for polytechnic admission after their secondary school education. They subsequently apply to polytechnics using their vocational results.								

It can be challenging to look at the average results, given that students DMR came from a wide range of academic abilities (LAS scores). There were a handful of 'better' students (i.e. low LAS of 7-9) compared to those near the cut-off LAS for DMR intake (i.e. maximum LAS of 25). The mixing of students was based on other admissions criteria beyond the scope of this discussion. Suffice to say that the team had no control over this matter.

An interesting result comes from comparison the marks for class 2A/24 (experimental group) and 2A/23 (control group) whereby the 2 classes of students have similar academic abilities. Here class 2A/24 clearly improved from CA1 to CA2 while class 2A/23 moved in the opposite direction. It can be interpreted that 2A/24 had learnt better from the interventions despite the lack of statistical significance. However, this cannot be substantiated by the results for CA3 Part 1. All 4 classes in fact had similar mean scores but it is notable that the standard deviation for 2A/23 is much larger than 2A/24.

Also, the results also showed that broadly, despite the outcomes indicated on the SFTS scores (Table 3) students from the experimental groups still made good progress in moving from CA1 to CA2, although one needs to be mindful that the standard deviations for both classes 2A/21 and 2A/24 are still fairly large. Students from control group 2A/22 also performed well from CA1 to CA2 and this can be attributed to the stronger academic ability of these students. Performance for class 2A/23 remained anomaly especially all have the same academic ability at LAS 19.
We did not manage to delve deeper into individual student scores, again due to time constraint. What we did next was to look at the reflection journals submitted by students from the

experimental groups, which is presented next.

Students' Reflection Journal Entries

Lastly, we studied entries in the Term 1 reflection journals from students from the experimental groups. A total of 23 students (out of 26) submitted. The entries were analyzed for key themes, of which 3 were identified as follows:

a. Following procedures blindly with little real understanding of the systems and process hence feeling stressed and panicked as the mind went blank and unable to effectively think of the next course of action.
b. Not leveraging on teamwork by seeking team members' assistance to analyze the situation and acquire the essential information for critical evaluation to achieve a solution.
c. Not paying attention to the system's parameters that provide essential information on the operational state of the system or machinery, to critically evaluate and deduce the cause of potential failure warning via sounding of alarms.

Interestingly, a study of the entries in the Term 2 reflection journals from the same students revealed themes similar to the above: feeling stressed from having too many sequences and procedures to recall for execution. However, students in general do demonstrate greater composure when visual and audible alarms go off; and they reported that they we better able to acknowledge the alarms and carry out the proper diagnostics of the scenarios:

a. review appropriate parameters
b. think through possible causes and
c. seek inputs from teammates.
d. based on the 3 points above apply rectification steps to resolve the issues.

An insight that we obtained from the reflection journals is the influence of teamwork. It is worth noting that all exercises in Terms 1 and 2 were conducted in groups, but the assessments are based on individual efforts. It can be speculated that some students in the experimental group experienced challenging team dynamics that affected their perceived failure tolerance – positive or otherwise. We did not require students from the control group to submit reflection journals, we do not know if this group's experience with teamwork in carrying out the tasks.

Besides teamwork, another insight we obtained from the reflection journals that we did not get from looking at average scores of SFTS and KAI Inventory scales; and the average marks for the assessment components is the disposition of *each individual student* towards failure. Table 5 showed the reflection journal entries from 2 students "Ethan" and "Ryan" from the experimental group, selected on basis of demonstrating evidence of learning from the interventions administered.

It is worth noting that the 2 students are also academically stronger, a finding which we validated by going back to check on their profile and academic scores for the graded assessments. Due to time constraint, we did not manage to extract the individual students' SFTS Score and KAI Inventory Score.

Table 5. Comparison of reflection journals from 2 students in Term 1 and Term 2

Student	Term 1 Reflection Journal	Term 2 Reflection Journal
“Ethan” (real name withheld at student’s request)	*“Stay calm and composed, ensure correct procedures were made and also regularly check on the operational readings like temperature, pressure, level, flow rate, voltage, frequency, etc. In real life, check if equipment has been properly checked and maintained in the past few days/weeks. If equipment had been sufficiently checked and maintained, equipment breakdown/malfunctions should occur less frequently.”*	*“There are some factors outside of our control that we cannot possibly predict, even though we did everything correctly. However, we can learn from this and find better ways to improve on how fast we can identify the problems as well as maybe think of ways to find a pattern so that we can predict such problems if they arise in the future.”*
“Ryan” (real name withheld at student’s request)	*“Before I encountered the situation, I was feeling proud because I managed to do it well during practice. But during the process, many alarms started to ring and I found it stressful because I didn’t know what is the main problem. After understanding the situation with the help of teammates I managed to overcome the stress and worked on solving the problem.”*	*“When audible and visual alarms go off during synchronization of generators, do not panic or be shocked, stay calm to check carefully and ensure proper transfer of power before proceeding to disconnect and shut down outgoing generator.”*

DISCUSSIONS AND MOVING FORWARD

The entire endeavor had been a great learning experience for all 3 authors. We started off with very ambitious plans for this pilot run, while acknowledging the challenges that underpin what we can achieve within a semester, namely in terms of the time constraint, which readers will have noticed this being mentioned multiple times in the earlier section. We meant this work to be a “proof-of-concept” initiative, adopting the approach of “fail fast, fail early” to learn from the pilot run as much as possible; as we are all new to training students to learn from deliberate failure when operating complex systems.

Overall, based on the performance, results, and feedback of students in the experimental group, it can be said that the pilot run of using deliberate failure interventions shows promise of improving students’ learning using deliberate failure, but much remained to be improved. The challenges are multi-faceted, and some key areas are discussed below.

Revamp of the Diploma in Marine Engineering Program

At the time of this writing, the entire DMR curriculum is under review to better streamline the delivery of the program to meet stakeholder and institutional requirements. There are excellent opportunities to also revamp some modules *especially those is the first year to include foundational work to shape students’ view towards failure* (Cheah, 2023). Some of the key objectives of the redesign of the DMR program towards an integrated curriculum are:

- Identify gaps in students’ outcomes required by the IMO CoC and hence rectify the shortfall in coverage and achieve better alignment
- Identify coverage of existing fundamental skills and attitudes in current program structure, such as teamwork and communication to be leveraged on in supporting learning from failure

- Identify opportunities in other modules to better prepare for the learning tasks in the module “Marine Engine Room Simulator Training” to “offload” the “preparing the mind” stage coverage in this module (as described in Table 1 for Term 1). This will free up time in the module to engage students deeper in learning from failure (Table 2 for Term 2). These other modules can, for example: (a) tap on growth mindset to build up students self-efficacy and modify their perception of failure as a negative outcomes; and (b) reinforce students’ understanding of the various relationships between process variables in the operation of a s ship’s engine.

Redesign of Module “Marine Engine Room Simulator Training”

Moving ahead, more specifically on the module “Marine Engine Room Simulator Training” itself, the DMR team plans to carry out the following improvements to the module:

- Focus module delivery on the 4 major scenarios
  (1) Cold ship to ship on own power (i.e. 1 main generator running)
  (2) Own power to harbor condition
  (3) One Hour Notice to Departure for Preparing propulsion plant from Harbor condition to Ready for Departure
  (4) Watch Keeping Practice when the ship is sailing at full away sea state
- For each of the scenarios, facilitator will select and load suitable intervention(s) with deliberate failures. A facilitation guide will be prepared to help lecturers manage the learning process in a consistent manner
- Update module syllabus to capture learning outcomes for skills and attitudes

Developing Lecturer Competency in using CDIO and Facilitating Learning from Failure

It is worth pointing out that most SMA staff in general, and those directly in the experimental group in particular, are not familiar with CDIO. A series of professional development workshops had been planned for staff from SMA, to firstly acquaint them with them with the fundamentals of CDIO. Subsequent training will focus the concepts of learning from failure, the CDIO Approach towards designing an integrated curriculum, designing intervention using CDIO integrated learning experiences and learning assessment, among others. The goal is supporting the revamp of the DMR Program mentioned above.

SMA staff will also need to be trained to facilitate students learning in a different manner, moving away from the current practice. The importance of having students think differently, and to embrace learning from failure will be emphasized.

Conduct Another Round of (Better planned) Intervention

it is important to bear in mind the need for careful use of failure interventions to avoid “failure” fatigue, discouragement, and eventually de-motivation. The module will be run again for another 4 classes of students in coming semester. If necessary., we could continue to revisit the results obtained from this work, to drill down into details at the level of each student to gain better insights from each one of their learning experience that can shed more lights to improve for the next run.

With changes made to the module as mentioned earlier, we can plan for better interventions that will include a short briefings to all students, on the importance of critical thinking, and the “new” way of learning that comes with the module, which include the following:

- Challenge questions can be built into the learning tasks, requiring all students – regardless of if they are in experimental or control group – to answer them.
- Existing assessment rubrics will be improved upon to enhance consistency in grading by different lecturers taking the different classes.
- A focus group discussion will be planned into the intervention at the end of the semester.
- The questions used in the reflection journal can be crafted in more specific manner, by pointing to learning from failure; based on the generic format suggested by Gibbs.

Last, we also need to be mindful of the multitude of surveys students are already asked to complete on top of the usual student feedback surveys and teamwork surveys. This is especially true in SP, where there are additional institutional-level longitudinal surveys on self-directed learning, with a pilot run already in progress, that will eventually be extended to all students. To allow us to effectively investigate influence of teamwork in learning from failure in a group setting, we can leverage of the existing teamwork surveys to include additional (and specific) questions pertaining to learning in this module.

CONCLUSIONS

This paper shared how the pedagogy for learning from failure is being implemented in a Marine Engineering program. The results are, however, inconclusive. Out students from the experimental group with additional activities on tackling failure issues showed a decrease in failure tolerance. Cross-checking evidence from other sources namely reflection journal, and assessment marks

Our study did show that when it comes to matters related to learning from failure, at least for the case of dealing with complex systems, there is a need to address each student's disposition towards failure as a mechanism for improving learning, especially when we are dealing with students of wide demographic make-up and learning abilities. This work and yield a lot of insights into ways to engage students to learning from deliberate failure. Refinements to the interventions introduced in this pilot run had been identified, as more research into this way of student engagement is implemented in this program will continue to be explored.

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BIOGRAPHICAL INFORMATION

Sin-Moh Cheah is the Centre Director of the SP-CDIO Centre for Innovative Teaching and Learning; under the Department of Educational Development, Singapore Polytechnic. He has more than 16 years of experience implementing CDIO in the Diploma in Chemical Engineering curriculum and had conducted various CDIO workshops for universities in Asia for various disciplinary programs.

David Tay, a certified Marine Engineer, is a Specialist (Teaching & Learning) & Senior Lecturer with the Singapore Maritime Academy at Singapore Polytechnic with 15 years of experience as educator and trainer for Pre-employment and Continuous Education Training in the Maritime Sector. He assists the Course Chair in driving the DMR curriculum revamp using the CDIO Framework.

Hong Lin Liew, a certified Marine Engineer serves as the Course Chair for the Diploma in Marine Engineering of the Singapore Maritime Academy. With 5 years of experience as an educator and trainer, his primary area of interest lies in redesigning the DMR curriculum using the CDIO Framework to enhance program learning outcomes required by the professional bodies, and in motivating underperforming students.

Corresponding Author

Sin-Moh Cheah
Department of Educational Development,
Singapore Polytechnic
500 Dover Road, Singapore 139651
smcheah@sp.edu.sg

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Appendix 1: SMA Marine Engine and Simulator

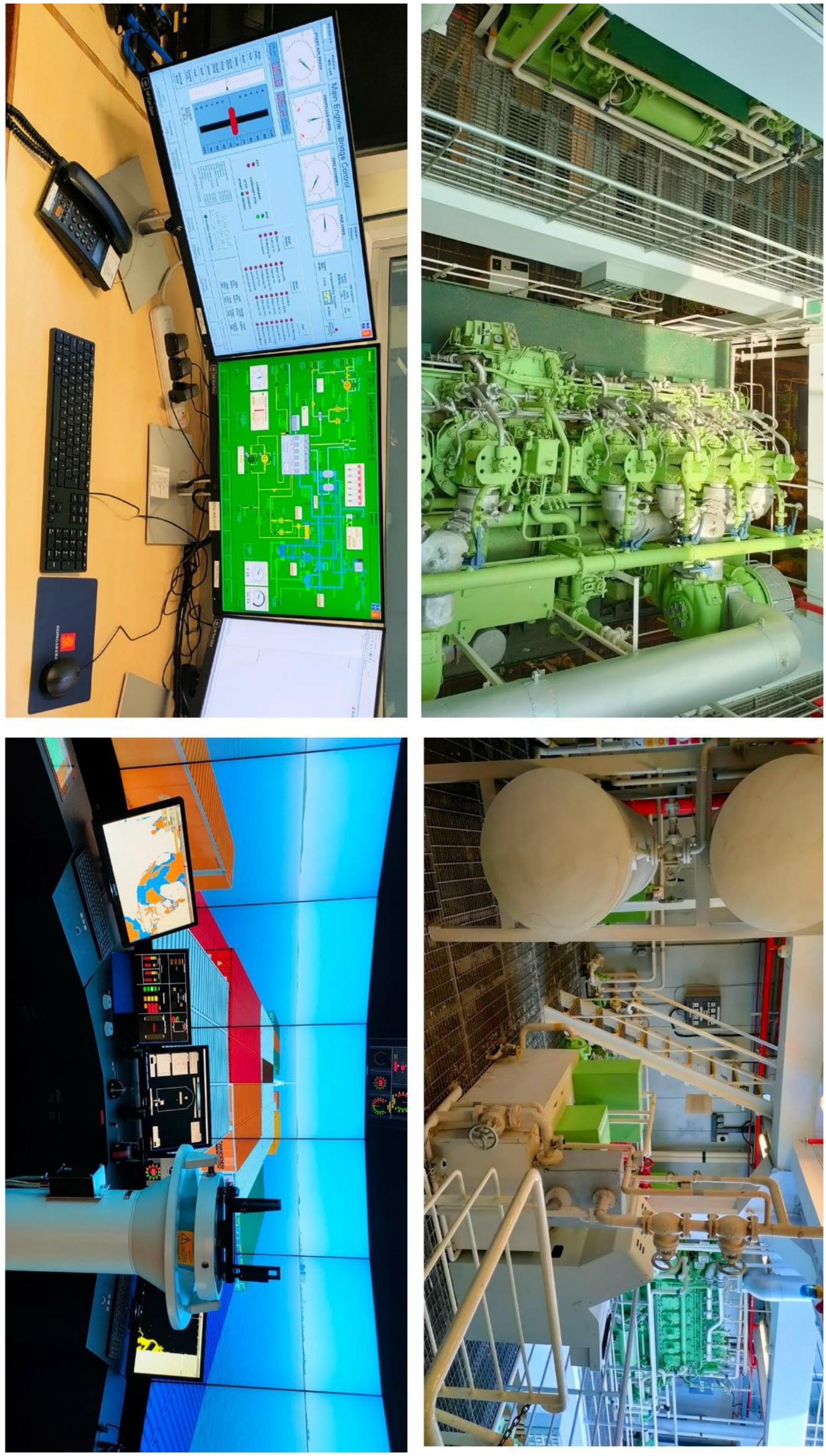

Figure A1. Physical mock-up of Engine (above) and Simulator Console with Immersive Environment (below)

Appendix 2: Learning progression for Marine Engine Room Simulator Training

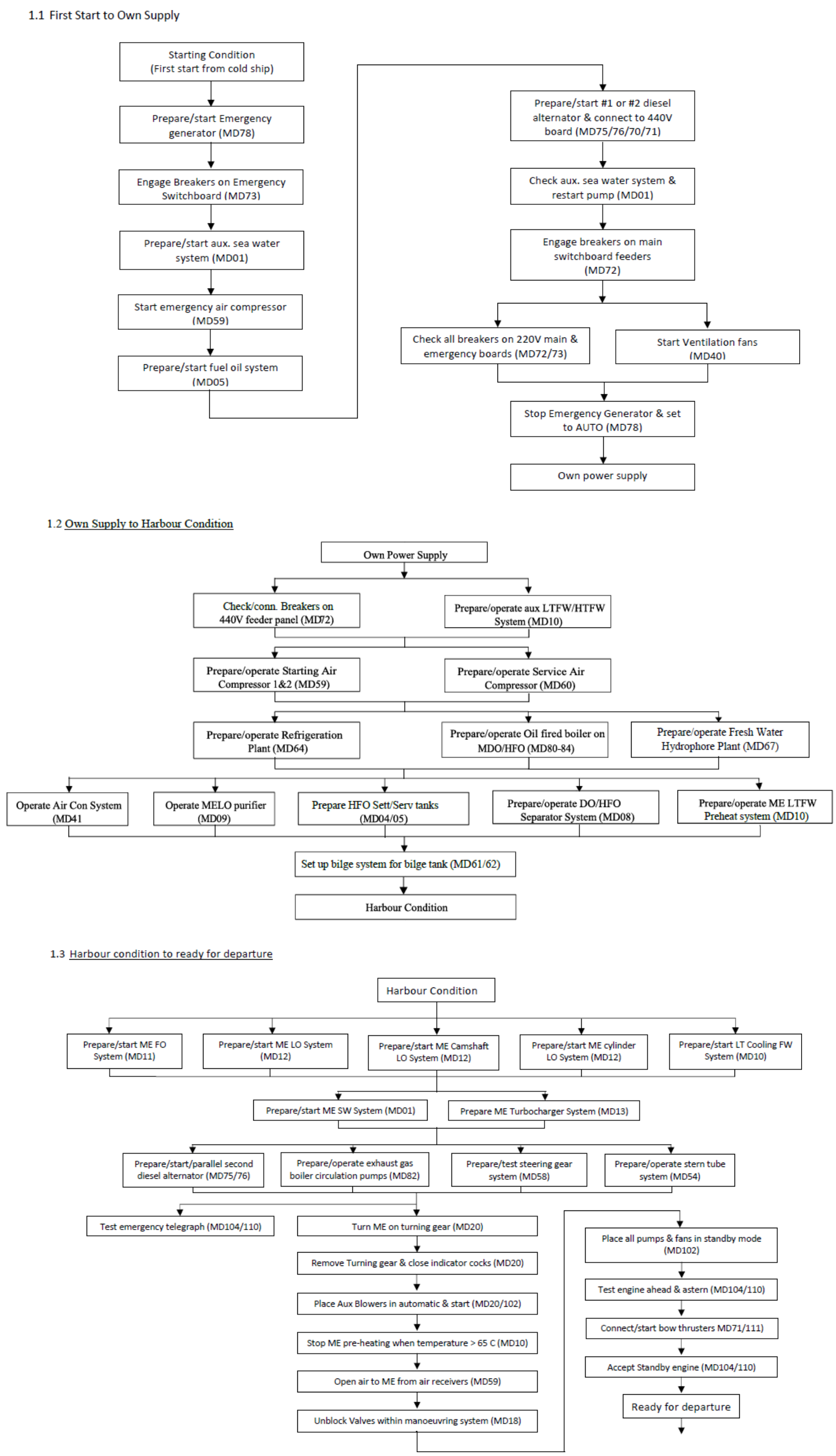

Figure A2. Learning progression over a semester of study

Appendix 3: IMO STCW Code Section A-111/1 Chapter III (STCW 2010 Res 2)

Mandatory Minimum Requirements for Certification of Offers in Charge of an Engineering Watch in a Manned Engine-Room or Designated Duty Engineers in a Periodically Unmanned Engine-Room

Training

1. The education and training required by paragraph 2.4 of regulation III/1 shall include training in mechanical and electrical workshop skills relevant to the duties of an engineer officer.

Onboard Training

2. Every candidate for certification as officer in charge of an engineering watch in a manned engine-room or as designated duty engineer in a periodically unmanned engine-room of ships powered by main propulsion machinery of 750 kW or more whose seagoing service, in accordance with paragraph 2.2 of regulation III/1, forms part of a training programme approved as meeting the requirements of this section shall follow an approved programme of onboard training which:
    1. ensures that, during the required period of seagoing service, the candidate receives systematic practical training and experience in the tasks, duties and responsibilities of an officer in charge of an engine-room watch, taking into account the guidance given in section B-III/1 of this Code;
    2. is closely supervised and monitored by a qualified and certificated engineer officer aboard the ships in which the approved seagoing service is performed; and
    3. is adequately documented in a training record book.

Standard of Competence

3. Every candidate for certification as officer in charge of an engineering watch in a manned engine-room or as designated duty engineer in a periodically unmanned engine-room on a seagoing ship powered by main propulsion machinery of 750 kW propulsion power or more shall be required to demonstrate ability to undertake, at the operational level, the tasks, duties and responsibilities listed in column 1 of table A-III/1.
4. The minimum knowledge, understanding and proficiency required for certification is listed in column 2 of table A-III/1.
5. The level of knowledge of the material listed in column 2 of table A-III/1 shall be sufficient for engineer officers to carry out their watchkeeping duties. *
6. Training and experience to achieve the necessary theoretical knowledge, understanding and proficiency shall be based on section A-VIII/2, part 4-2 Principles to be observed in keeping an engineering watch, and shall take into account the relevant requirements of this part and the guidance given in part B of this Code.
7. Candidates for certification for service in ships in which steam boilers do not form part of their machinery may omit the relevant requirements of table A-III/1. A certificate awarded on such a basis shall not be valid for service on ships in which steam boilers form part of a ship's machinery until the engineer officer meets the standard of competence in the items omitted from table A-III/1. Any such limitation shall be stated on the certificate and in the endorsement.
8. The Administration may omit knowledge requirements for types of propulsion machinery other than those machinery installations for which the certificate to be awarded shall be valid. A certificate awarded on such a basis shall not be valid for any category of machinery installation which has been omitted until the engineer officer proves to be competent in these knowledge requirements. Any such limitation shall be stated on the certificate and in the endorsement.
9. Every candidate for certification shall be required to provide evidence of having achieved the required standard of competence in accordance with the methods for demonstrating competence and the criteria for evaluating competence tabulated in columns 3 and 4 of table A-III/1.

Near-Coastal Voyages

10. The requirements of paragraphs 2.2 to 2.5 of regulation III/1 relating to level of knowledge, understanding and proficiency required under the different sections listed in column 2 of table A-III/1 may be varied for engineer officers of ships powered by main propulsion machinery of less than 3,000 kW propulsion power engaged on near-coastal voyages, as considered necessary, bearing in mind the effect on the safety of all ships which may be operating in the same waters. Any such limitation shall be stated on the certificate and in the endorsement.

* The relevant IMO Model Course(s) may be of assistance in the preparation of courses