EFFECT OF STUDENT MINDSET ON FAILURE TOLERANCE IN LEARNING FROM DELIBERATE FAILURE

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This paper shares the work done in investigating possible effect of growth mindset in influencing students' perception of failure. This is expressed in the form of failure tolerance, which is measured using a validated survey instrument to indicate to extent to which a failure is seen as an opportunity to learn and improve. The study was carried out with a group of Year 2 students taking the module "Marine Engine Room Simulator Training" from the Diploma in Marine Engineering. The students undergone a range of learning tasks over a period of one semester; using computer simulation that mimics tasks they are expected to perform in the real world when they joined the marine industry upon graduation. These learning tasks were designed using the CDIO Framework with "build-in" elements that will purposefully create challenges with potential that students will not achieve the desired performance outcomes, hence the term "learning from deliberate failure". The students had earlier learnt of growth mindset in Year 1 from another module. The hypothesis is that "Growth mindset can positively improve students' failure tolerance". Surveys were administered before and after the learning tasks using the School Failure Tolerance Scale, along with questions related to assess growth mindset. Students were also required to write 2 reflection journals on their learning experiences, which were analyzed for their sentiments. This paper first provides a brief introduction to learning from deliberate failure, and literature reviews on failure tolerance and growth mindset, followed by the methodology known as "design-based research" which is used to design the series of learning tasks with elements of deliberate failure". The paper then provides a summary of an earlier effort on learning from deliberate failure that preceded the work reported on in this paper, to provide the proper context of learning, and outlined the scope of this paper. The current work is then covered in details; including findings from student surveys and reflection journals of their learning experience. This was followed by an exploration of areas of improvement in light of the findings.

Keywords: *Deliberate Failure, Growth Mindset, Failure Tolerance, Design-based Research, CDIO Framework*

Introduction

Learning from deliberate failure – often shortened to learning from failure – is a pedagogy whereby the lecturer purposefully (deliberately) design student learning tasks that will produce outcomes not expected, i.e. a failure. (Cheah, 2023). The rationale for doing so is to engage students in deeper learning through reflection on the learning process, that gradually shapes the students' view to see failures as something not to be avoided during learning. Learning from failure is the dominant approach to training of professionals working in high-risk industries such as power plant (including nuclear), airlines, maritime, and chemical processing. Such industries operate on 'complex systems' (Cook, 1998, 1999, 2020) with the following characteristics: (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 'causes' limit the effectiveness of defenses against future events. In these industries, the consequence of a failure if unmitigated, is often catastrophic. Failure-free operations thus require experience with failure; and timely respond with the proper corrective actions. Training is often done using simulators, where engineers and technicians practiced on handling various failure scenarios.

Failure Tolerance and Growth Mindset

Failure is defined as an outcome that deviates from desired results – a lack of success (Edmondson, 2023). Learning from failure does not happen on its own. Rather, it is a skill that needs to be learned and practiced. Failure tolerance is defined as "a tendency to respond to failure in a relatively constructive manner" (Kim & Clifford, 1988). Studies by Clifford, et al (1988) had shown that failure tolerance is a reliable predictor of responses to failure. Failure tolerance can be measured using the School Failure Tolerance Scale (Clifford, 1988), or SFTS in short. Subjects with high failure tolerance responded more constructively to failure than did subjects with low failure tolerance (Kim & Clifford, 1988).

Growth mindset (GM) is the belief that your abilities, talents, and skills can be developed over time with effort, learning, and dedication (Sousa, 2023). Dweck (2006) classifies two distinct mindset groups on a continuum: Growth and Fixed. Those inhabiting a fixed mindset tend to believe that skills and abilities are innate. In other words, one is born smart or talented. Individuals with a fixed mindset tend to view failure as permanent, generally choose to pursue easier tasks and are less likely to persist in the face of challenges. Growth mindset individuals, on the other hand, typically see failure as a chance to learn, embrace challenges as a way to experiment and use creative problem-solving. As noted by Dweck (2015): "In a growth mindset, people believe that their most basic abilities can be developed through dedication and hard work – brains and talent are just the starting point. This view creates a love of learning and a resilience that is essential for great accomplishment."

Given the above, it is reasonable to expect that students with growth mindset will be more open-minded with respect to handling failure, i.e. see failure as an opportunity to learn and improve (Mueller & Dweck, 1998). Indeed much of the literature expounded on the need to develop growth mindset in view of its many advantages. Mindset interventions in particular, were found to be very useful in promoting students' growth mindset (Kapasi & Pei, 2022). Shahagun et al (2021) proposed a pedagogy for growth mindset for higher education and showed that students exposed to the growth mindset teaching pedagogy demonstrated improvement in their growth mindset beliefs. However, one area that is not well studied is the relationship of mindset and resilience to failure.

Methodology: Design-based Research

The approach we adopted is termed design-based research (Reeves, 2006). It aims at developing empirically grounded theories through combined study of both the process of learning and the means that support that process (diSessa & Cobb, 2004; Gravemeijer, 1998). Barab & Squire (2004) provided a broad and generic definition that encompasses most variations on the terminology:

"*A series of approaches, with the intent of producing new theories, artefacts, and practices that account that account for and potentially impact learning and teaching in naturalistic settings*".

Anderson & Shattuck (2012) suggested that a quality design-based research is defined by the following:

- Being situated in a real educational context
- Focusing on the design and testing of a significant intervention
- Using mixed methods
- Involving multiple iterations
- Involving a collaborative partnership between researchers and practitioners
- Evolution of design principles
- Practical impact on practice

One of the primary advantages of design-based research is that it requires practitioners and researchers to collaborate in the identification of real teaching and learning problems, the creation of prototype solutions based on existing design principles, and the testing and refinement of both the prototype solutions and the design principles until satisfactory outcomes have been reached by all concerned. Design research is not an activity that an individual researcher can conduct in isolation from practice; its very nature ensures that progress will be made with respect to, at the very least, clarification of the problems facing teachers and learners, and ideally, the creation and adoption of solutions in tandem with the elucidation of robust design models and principles.

Reeves (2006) suggested a 4-stage process as shown in Figure 1. He further noted that the most noteworthy of design-based research is that design researchers do not emphasize isolated variables, even though they did focus on specific objects and processes in specific contexts. Instead, they try to study those as integral and meaningful phenomena. Because of its iterative and consultative nature, design-based research is unlikely to engender researcher-imposed directives on how problems should be approached (Herrington & Reeves, 2011). It addressed one of the criticisms of contemporary education research which Anderson (2005) expressed as "…those types of research that unilaterally descend for testing in a classroom and then disappear with the researcher once the experiment has been concluded". Quite the contrary, design-based research has the capacity to change the ways that researchers and practitioners together investigate and solve significant educational problems in powerful ways. Again, as noted by Anderson (2005): "Design-based research does not seek for universal solutions but rather for deep understanding of innovations and the factors that affect improvement in local contexts".

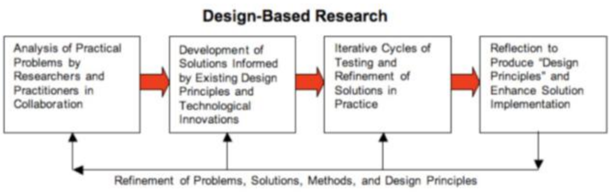

Figure 1. Stages in Design-based Research

Scope for This Paper

The present work is built upon earlier effort by Cheah (2023) who introduced the pedagogy for learning from deliberate failure based on the CDIO Framework. This is followed by a pilot run in Semester 2 of Academic Year 2023/2024 involving Year 2 students from Singapore Polytechnic's (SP) Diploma in Marine Engineering (DMR). The main outcome of DMR is to produce skilled manpower for the marine industry, based on Standards of Training, Certification and Watchkeeping (STCW) Code Table A-III/1 from the International Maritime Organization (IMO, 2010).

The pilot run featured a series of learning tasks lasting a whole semester in the DMR 60-hour core module entitled "Marine Engine Room Simulator Training". Design interventions used include a range of learning tasks using simulator that mimic the preparation of a commercial crude oil tanker to set sail from "cold" condition, to keeping watch at sea and subsequently bring it back to port (Cheah et al, 2024) . The study divides students into 2 groups: experimental group (44 students) who received various design interventions and control group (33 students) who were guided through the process by the lecturer. Their SFTS were computed based on their responses to pre- and post-test surveys.

In contrary to our expectation, the outcome from the pilot run showed the reverse result: the control group showed an improvement in failure tolerance compared to the experimental group; although statistically the difference is not significant. This can be explained as the control group, having received guidance from the faculty throughout the semester, developed a false sense of confidence, hence reported a higher failure tolerance.

Responses from the reflection journals also proved to be not very useful, as we had used a generic set of questions based on the Gibbs Reflection Cycle (Gibbs, 2013) and students in general responded poorly. That notwithstanding, we gained an important insight that guided the design of current study: that some students remained positive when encountering failures during the various interventions. It then dawned on us that the DMR students had been taught growth mindset in a stakeholder module "Education and Career Guidance 2" (ECG2) within the same semester as "Marine Engine Room Simulator Training". One of the activities in ECG2 requires students to score their own mindset by answering a set of questions adapted from Dweck (2006).

Explanation of Current Work Done

For the current work, which ran for Semester 1, Academic Year 2024/2025, we hypothesized that students with greater growth mindset will be more failure tolerant. Since growth mindset is scored individually for each student, we henceforth conclude that it is necessity to analyze the SFTS scores on an individual basis. We are interested in finding out if high score for GM correlates with high SFTS scores; as well as to continue investigating if the design interventions helped to improve students' failure tolerance.

As required by design-based research, we made some changes for the current study based on learning gained from the pilot run. We also made some changes in the timing when activities with deliberate failure are introduced: namely in the second term, hence freeing up time for students to familiarize with the ship engine and simulator. The learning tasks remained unchanged. Table 1 showed a summary of the students' learning experience for the current study. Table 2 provides brief explanation of each learning task with elements of deliberate failure.

It also worth noting that for current work, because the cohort size of students taking the module "Marine Engine Room Simulator Training" is small – only 41 students in total. This, and the reason of perceived competence mentioned above, led us to decide to do away with the control group.

Table 1. Lesson Plan for Term 1 and Term 2 Activities

Term 1 – Familiarization (NO INTERVENTION INTRODUCED)		
Week	Brief Description of Activity	Key Remarks
1	Cold Ship Start-Up (1) *Familiarization with Engine Room and Power Plant Trainer*	• For all these exercises, no interventions were introduced. • The systems and operational sequences were explained and demonstrated and thereafter the students practiced them, • Instructors step in when students seek help to resolve when they encounter failures.
2	Cold Ship Start-Up (2) *Seawater Cooling Systems Fresh Water Cooling Systems*	
3	Cold Ship Start-Up (3) *Compressed Air System*	
4	Main Power Start-Up *Diesel Generator Start-Up and Paralleling*	
5	Auxiliary System Start-Up *Fuel Oil System Lube Oil System*	
6	Auxiliary Boiler Start-Up *Steam Generation*	
7	Continual Assessment 1 (INDIVIDUAL, 1-hr, 40%): Learning Journal All students submit a report comprising answers to questions posed in each activity for the past 6 weeks. All students are to submit a short reflection report, answering specific 4 questions posed.	
8, 9-11	Mid-semester Test Week – No lesson for this module, followed by 3-week Term Break	
Term 2 – Operation (WITH INTERVENTIONS INTRODUCED)		
Week	Brief Description of Activity	Interventions
12	*Revision of Term 1* Start of Parallel Generator – *after going through the steps in Term 1*	See Table 2
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.	
14	"One Hour Notice" Preparation to leave port and set sail *Lube Oil Purifier Start up*	See Table 2
15	Repeat of "One Hour Notice" to leave port and set sail	See Table 2
16	Out at Sea: Keeping watch duties and responding to alarms	See Table 2
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. Students reflect on their experiences and submit individual reflection journals.	
18	Set Aside for Make-Up Lessons, if needed	
19-20	Semestral Examination (2 weeks) – Not Applicable for this Module	

To avoid survey fatigue among students, we embedded a set of questions related to GM along with the questionnaire for SFTS. Lastly, we also retained the submissions of reflection journals by individual students, but this time we provided them with the following guidance questions to help them focus on key issues to help us with subsequent analysis.

Q.1 What was the "failure" experience?

Briefly describe what went wrong or failed when you carried out the exercise (from starting of main generators to preparing systems for main engine to start) during the Engine simulator lessons.

Q2. What your feelings & thoughts about the experience?

Briefly describe how you feel (e.g. emotion, stress, anger, anxiety or excitement) when you encountered the "failure" situation. In your answer, please discuss if you see benefits from such failure; or how did you manage the feeling that arisen. You may include before, during, and after the encounter.

Q3. What do you think contributed to the situation?

Consider what actions taken by you and/or other people or actions that should have been taken but not done; that have contributed to the situation.

Q4. What did you learn and what could you have done differently?

With references to your answers to Questions 2 and 3 earlier, describe what you learned from this situation, for example, how it changed your view about failure or focus on following the procedures, etc. Also consider if there are skills that you think you need to develop to better handle the situation.

Table 2. Learning Tasks with Deliberate Failure

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 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 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.
Example 4: 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.

Results and Discussions

The SFTS and GM combined survey was first administered before students embarked on the learning tasks of Table 2 (pre-test) and again after they had completed the learning tasks (post-test). All 41 students responded to the pre-test, but only 31 responded for the post-test. Tables 3 and 4 showed the SFTS and GM scores from the 2 surveys; and correlation analysis to investigate possible relationship between SFTS and GM respectively. All data are based on same number of respondents (N = 31) for consistency in comparison. Student identities were anonymized before analysis.

Table 3. Pre- and Post Test Survey Results

N=31	Pre-Test	Post-Test	p-value
SFTS	3.020	3.017	0.9750
GM	3.068	3.154	0.5410

Table 4. Correlation Analysis (Pre- and Post-Test)

N=31	Pre-Test		Post-Test	
	SFTS	GM	SFTS	GM
SFTS		0.340 p=0.0294		0.293 p=0.1100
GM	0.340 p=0.0294		0.293 p=0.1100	

The results, unfortunately, are inconclusive. Contrary to expectation, failure tolerance after intervention appeared to have decreased instead; albeit only slightly and the change is statistically insignificant. Likewise, the slight increase in growth mindset, while expected, is also statistically insignificant. The observed changes between pre-test and post-test numbers therefore can be attributed to random chance and no conclusion can be drawn. The results when reviewed alongside the reflection (see later) seemed to indicate that the emotional impacts associated with the stress and time-pressure are influencing the SFTS ratings given. Students in general do not respond to the SFTS questions in an objective manner. This is perhaps not too surprising, as experincing failure is not pleasant for most people: failure tends to hurt one's ego and violate one's beliefs and expectations.

Likewise, the relationships between failure tolerance and growth mindset, while showing slight positive correlation, did not lend themselves to definitive explanation: it was statistically significant for the pre-test but not the case for the post-test. The results can be attributed to the small sample size. Only 31 out of 41 responses were used. This is because for the post-test, some students did not complete the survey and/or reflection journal.

Next, we turn to the reflection journal. Here we made use of all respnoses submitted, as we wanted to glean as much as possible on students' learning experiences. For the analysis, we make use of the free version of ChatGPT to help us in performing sentiment analysis. The results are rather comprehensive, and only key findings are summarized here, as shown in Table 5. For more details, including the prompts used, use the LINK here.

Table 5. Pre- and Post Test Survey Results

Phase	Dominant	Focused	Key Features
Before Intervention	Negative (stress, frustration, confusion)	What went wrong?	Feeling of failure dominates
Transition	Mixed (neutral, analytical)	Why did it happen?	Recognizing mistakes and causes
After Intervention	Positive (growth, confidence, motivation)	What did I learn?	Improved problem-solving, teamwork, and confidence

Some of the findings that contributed to Table 5 are now briefly discussed. Firstly and most importantly, we are mindful of the careless use of Generative AI tools in performing such an analysis. We in fact noted cases of student quotes produced by ChatGPT that cannot be found in the source documents (i.e. student responses in the journals). Therefore, we carefully checked the outcomes from ChatGPT in this current study and is satisfied that the findings presented did sufficiently captured the sentiments expressed in the journals. These are now elaborated below.

At the earlier phase of their learning, students express frustration, stress, and confusion as their primary emotions. These negative emotions stem from: (a) Technical issues (e.g. forgetting to open valves, difficulty locating parts), (b) Lack of familiarity with systems (e.g. not knowing required sequences), (c) Communication breakdowns (e.g. unclear instructions, lack of teamwork), and (d) Feeling rushed or overwhelmed (e.g. alarms causing panic, trying to do too much at once).

Through reflections, students analyzed the failure and began to recognize some contributing factors. There is a shift from frustration to understanding the root causes, with a range of mixed of negative and neutral sentiments. Key realizations include: (a) Many failures resulted from rushing and not following proper sequences, (b) Lack of familiarity with the system and its components, and (c) Need for better communication and planning which could have prevented confusion.

From the post-test reflections, we can see evidence of increasing positive sentiments from lessons learnt, as demonstrated in the post-test reflection. Students show a more positive and constructive mindset, focusing on growth and improvement. Common themes include: (a) Failure as a learning opportunity, recognizing that failure helped them improve, (b) Better problem-solving skills arise from systematic thinking and patience, (c) Increased confidence and preparedness, i.e. better equipped to handle similar situations in the future, and (d) Improvement in teamwork and communication: better understanding of clear roles and leadership.

Possible Areas of Improvement

Several areas of improvement had been identified earlier by Cheah et al (2024). Some, such as changes to the timing in introducing learning interventions (in Term 2 only) and used of guidance questions for reflection, had been implemented in this current work. Some other areas of improvement are shared below: some reaffirmed the needs to revise aspects identified in the earlier pilot run but not yet implemented in this current study; others are fresh insights from this current study. Only the latter are discussed here.

Revamp of the DMR Program

This is an on-going effort aimed at the redesign of the DMR program towards an integrated curriculum using the CDIO Framework. Details are provided elsewhere by Cheah et al (2024).Suffice to repeat here is that key feature of the redesign effort is to "spread out" the coverage of basic skills and attitudes needed to support learning in general and learning from failure in particular, in other core modules prior to embarking on the module "Marine Engine Room Simulator Training". This will free up time in this module to facilitate the learning process to engage students in deeper learning from failure.

Redesign of Module "Marine Engine Room Simulator Training" and selected Learning Tasks

The reflection journal results had highlighted some challenging areas for students. An example is that of starting the generator. The revision allocated in Week 12 (see Table 1) may not be sufficient. The module team will review the learning design and time allocation for this segment. Video recording for this task can also be created to allow students to self-practice on their own, after learning the task in Term 1 and before embarking on the assessment in Term 2. Another area worthwhile looking into is to introduce a 'condensed' version of the combined SFTS-GM survey; using a reduced number of questions. We can also explore feasibility on expanding the teaching of growth mindset to include approaches to manage negative emotions in the face of perceived setbacks.

Change in Instructional Approach towards Facilitation

By and large, in order to ensure compliance with IMO requirements, the de facto training approach used is very instruction-directed: Faculty inform students what they need to do each step of the way, leaving very little room for critical thinking, troubleshooting and problem-solving. This is largely the approach taken in Term 1, in order to get students up-to-speed with understanding the simulator system. This can be supplemented with more "probing" questions, using "what if" scenarios to engage students in deeper learning. This can serve as useful approach to design professional development workshops for faculty. The use of prerecorded videos can again be very useful.

Use Student-centred Pedagogy: Collaborative Learning

We can use the CDIO approach to explicitly introduce elements of teamwork and communication into the learning tasks, to help students in managing these non-technical aspects of the process. This can be done using collaborative learning pedagogy whereby there are clear roles for each students and how everyone can contribute to the collective learning. Basic skills in teamworking and communication can be inculcated in other modules beginning from Year 1.

Conclusion

The work presented in this paper yielded the expected positive relationship between growth mindset and failure tolerance, but it is not statistically significant. More useful are the students' responses in the reflection journals, which showed a shift in disposition from the initial frustration with failures which is seen as a setback, to a gradual understanding that failures can serve a useful learning tool. We conclude that the endeavour is still a worthwhile one, as it yielded other valuable insights that can guide subsequent iterations of the learning tasks using deliberate failure using the design-based approach, guided by the CDIO Framework.

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