CHEMICAL PRODUCT DESIGN: A CASE STUDY ON 'LEARNING FROM FAILURE'

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ABSTRACT

The purpose of this paper is to illustrate the effectiveness of learning from failure to develop resilience, creativity and innovation in students and understand the interrelatedness between creativity and innovation and conformance to norm in the Diploma in Chemical Engineering program offered by Singapore Polytechnic. The paper first provides a brief explanation of chemical product design as the context for integrating conceiving, designing, implementing and operating skills into the program when CDIO Framework was implemented in 2008. Then, it examines how the Chemical Product Design pathway offers learning opportunities for students to engage in 'learning from failure' that meet the CDIO Learning Outcomes in Section 2.4 Attitudes, Thought and Learning. In this paper, failure refers to students undertaking multiple iterations of tasks, such as refining prototypes before achieving a successful outcome. This study uses a mixed-method approach to gain a holistic understanding of students' experiences in learning from failure. It affirmed that the Chemical Product Design pathway indeed developed students' tolerance for failure and resilience. Resilient students are more likely to persist through failure or challenges and continue refining their ideas and excel. The process of coping with failure not only strengthens students' problem-solving confidence but also supports sustained creativity and innovation. However, the strong emphasis on conformity within the broader chemical engineering program may have inhibited the growth of creative thinking to a certain extent. There is a need to provide psychological safety for students to experience failure and reframe how learning from failure could bring more benefits than harm to student learning.

KEYWORDS

Chemical product design, Learning from failure, Resilience, Failure Tolerance, Confidence, CDIO Standards 2 and 5

INTRODUCTION

The purpose of this paper is to illustrate the effectiveness of learning from failure to develop resilience, creativity and innovation in students and understand the interrelatedness between creativity and innovation and conformance to norm

The paper first provides a brief explanation of chemical product design as the context. Then, it examines how the Chemical Product Design pathway offers learning opportunities for students to engage in 'learning from failure'. In this paper, failure refers to students undertaking multiple iterations of tasks, such as refining prototypes before achieving a successful outcome.

The Chemical Product Design pathway was first introduced to the diploma program in Academic Year 2008 to integrate conceiving, designing, implementing and operating skills into the program when CDIO Framework was implemented (Cheah & Sale, 2010). The Chemical Product Design pathway is rarely included in most chemical engineering programs because the professional practice in chemical engineering necessitates strict adherence to established protocols, standard operating procedures and compliance with safety regulations. These requirements constitute a core element of the discipline's professional standards and directly influence the design and delivery of chemical engineering program to ensure alignment with industry expectations and regulatory frameworks. This emphasis on conformity and operational rigour contrasts with the Chemical Product Design pathway that encourages flexibility, creativity and innovative thinking. in the Diploma in Chemical Engineering (DCHE) offered by Singapore Polytechnic (SP). Thus, the research questions are (1) how learning from failure influences the development of resilience, creativity, and innovation in students and (2) how conformance to norms interacts with students' creativity and innovation when learning from failure.

CHEMICAL PRODUCT DESIGN PATHWAY

The 3-year DCHE program consists of chemical engineering domain modules, Common Core modules that develop emerging digital and human skills, basic sciences and mathematics modules, as well as Chemical Product Design pathway that leads to Capstone Project in Year 3. In this current iteration, the Chemical Product Design pathway in the DCHE program is illustrated in Figure 1.

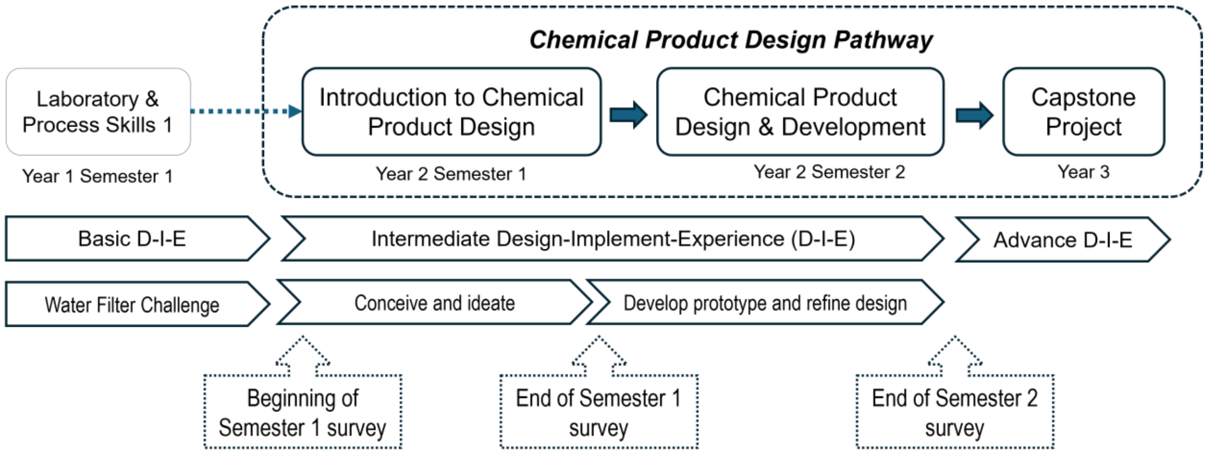

Figure 1. Chemical product design pathway in DCHE program

The integration of chemical product design provides students with learning opportunities to use chemical engineering principles to conceive and design useful products, greatly widening and enhancing DCHE graduates' competencies in 'Creativity, Innovation & Enterprise' and 'Self-Directedness & Personal Effectiveness' which are SP's graduate attributes. Hence, the Chemical Product Design pathway has gained increasing significance as means to develop creativity and design thinking competencies that graduates require to excel beyond mere conformity, preparing graduates to address complex challenges and develop innovative or novel solution for a more sustainable industry.

In addition to technical knowledge, the Chemical Product Design pathway cultivates attributes such as resilience, creativity, and innovation, which are transferable skills applicable across diverse job roles, including those outside the chemical engineering domain. To substantiate this value, the team undertook research employing a 'learning from failure' approach, collecting data to demonstrate that the pathway fosters these attributes and provides added value to students beyond a typical chemical engineering program. Hence, creativity and innovation were examined in contrast to conformance to norm because there could be a potential tension between fostering originality and adhering to established standards, which may be particularly relevant in chemical engineering that balances safety, precision and innovation.

The Chemical Product Design pathway has evolved through multiple redesigns to align with institutional priorities and industry needs. It is currently delivered mainly through two Year 2 modules: *Introduction to Chemical Product Design* module in Semester 1 and *Chemical Product Design & Development* module in Semester 2, as illustrated in Figure 1. Positioned within the framework of education for sustainable development, these modules integrate the United Nations Sustainable Development Goals as learning contexts (Cheah et al, 2022, and Oh et al, 2024). The first module develops foundational skills in product conception, evaluation, and design, incorporating advanced manufacturing and digital fabrication techniques alongside teamwork and creative problem-solving. The second module builds on this foundation by guiding students through prototype development, refinement of design specifications, and application of microcontrollers and sensors for automation, culminating in project proposals that extend into Capstone Projects. Students encounter failure during prototype development and design refinement, often due to limited experience and knowledge. In this process, they engage in reflective learning to identify what does not work and what works better. This iterative process of learning from failure fosters resilience, enabling students to recover from setbacks and develop greater tolerance for future challenges.

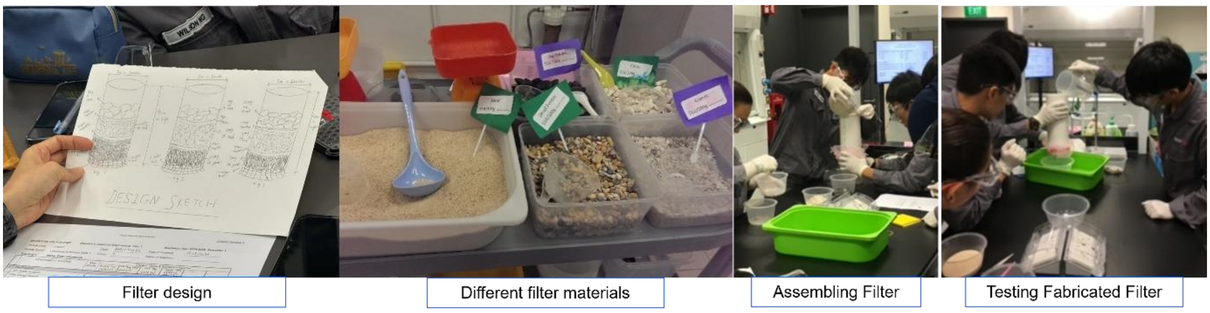

Figure 2. A Design-Implement-Experience in water filter challenge

In addition, a design-implement experience is integrated in one learning activity in the *Laboratory & Process Skills 1* module offered to first-year students in Semester 1 as a precursor to the Chemical Product Design pathway. This design-implement experience is grounded in product design principles, requiring students to construct a water filter based on a defined set of requirements and available resources, where multiple failure points were intentionally designed. Figure 2 illustrates students carrying out the Design-Implement Experience activity.

LEARNING FROM FAILURE IN CHEMICAL PRODUCT DESIGN PATHWAY AND ITS RELATIONSHIP WITH CDIO

The Chemical Product Design pathway is structured around the CDIO Innovation Process which is outlined in Section 4 of the CDIO Syllabus and 'learning from failure' enhances the development of personal and professional skills, specifically meeting the learning outcomes in Section 2.4 Attitudes, Thought and Learning of the CDIO Syllabus.

According to the Programme for International Student Assessment (PISA) 2019 survey, more than 70% of students in Singapore reported a fear of failure, a proportion that is notably higher than that observed among students in other participating countries (Teng, 2019). This finding suggests that students in Singapore experience comparatively elevated levels of fear of failure, which manifests as observable behaviours within the polytechnic context. So, the Chemical Product Design pathway presents opportunities for students to 'learn from failure' when they carry out prototype development and design refinement activities so that they become more tolerant to failure and resilient.

Resilience and tolerance to failure often develop through the experience of failure where students learn to adapt and recover from setbacks. Encountering failure challenges students' assumptions and forces students to develop coping strategies, such as reframing negative outcomes and seeking alternative solutions. Over time, these experiences strengthen emotional regulation, problem-solving skills and persistence, enabling the students to approach future challenges with greater confidence and flexibility. Learning from failure becomes a catalyst for growth and resilience, rather than negativity that should be avoided (Huang et al, 2024).

The phenomenon of failure in chemical product design differs fundamentally from failure in chemical process operation. 'Learning from failure' is generally perceived as an integral part of the creative process, fostering innovation through iterative refinement that enables students to become more resilient and tolerant to failure. Conversely, failure in chemical process operation should be avoided because it causes severe consequences, including safety hazards, environmental risks and economic losses. As a result, while design-related failure is tolerated and even used as a learning mechanism, chemical process operational failure is strictly controlled and minimised through established protocols and compliance to safety requirements.

In the Chemical Product Design pathway, students work in design teams consisting of 5 to 7 members per team to conceive and develop a prototype and refine the design to demonstrate its workability as shown in Figure 2. Failure could emerge under different scenarios depending on what students do and how they interact. The failures encountered by each design team would be different even though they are all given the same learning tasks. The level of failure tolerance for each team would depend on the willingness to make decision in the face of uncertainty (CDIO Learning Outcome 2.4.1), how much they could persevere when they face challenges would depend on their self-confidence (CDIO Learning Outcome 2.4.2) and their readiness to adapt to changes would depend on their level of resilience (CDIO Learning

Outcome 2.4.3). When students encounter failure, they will learn to reflect on their actions, embrace constructive feedback and manage their emotional responses.

In addition, students are guided to respond to setbacks ethically and with integrity (CDIO Learning Outcome 2.5.1). This has become increasingly important with the emergence of Generative Artificial Intelligence (Gen AI) where students must learn to critically evaluate the information and understand the ethical implication of AI use, including biases and misinformation. Lastly, students may become more creative and innovative to overcome the failure by reconsidering their assumptions and exploring alternative approaches in their design tasks (CDIO Learning Outcome 2.4.4).

METHODOLOGY

This study uses a mixed-method approach to gather a holistic understanding of students' experiences in learning from failure within the Chemical Product Design pathway. Quantitative and qualitative data were collected across two academic years (April 2023 to March 2025) to examine the changes in students' attitudes, resilience and creativity.

The quantitative phase employed the School Failure Tolerance (SFT) test by Clifford (1988) and the Kirton Adaptation-Innovation Inventory (KAI) by Kirton (1976). The SFT measures students' tolerance to failure, resilience and confidence while KAI measures confidence, creativity, innovation and conformance to norms. Data were collected at three points during the academic year, that is May 2023 (beginning of Semester 1), August 2023 (end of Semester 1) and February 2024 (end of Semester 2). Each measurement used a five-point Likert scale, with responses analysed using t-tests at 5% significance level to examine the developmental changes over time. The cohort size is 120 and the survey response rate ranges from 47.5% to 81.7%. Students were required to give their consent for the research team to collect data from them and they have the option of withdrawing from participating in the survey at any point.

To complement the survey data, multiple qualitative sources were triangulated to capture nuances of students' learning from failure experiences:

- **Focus Group Discussions (FGDs)** were conducted at the end of each academic year (February – March 2024 and February – March 2025) with students who participated in the survey. The FGDs explored students' emotional responses, coping strategies and perceptions of failure in design learning. These discussions revealed rich narratives about resilience, teamwork and self-reflection.
- Two structured **classroom observations** were conducted to document in-situ manifestations of failure and recovery behaviour in the learning environment. The first observation took place in January 2024 during the *Chemical Product Design and Development* module taken by students in Year 2 Semester 2. Students were observed engaging in prototyping tasks such as 3D printing the circuitry design, where instructors emphasised safety, correctness and iterative improvement. The second observation was carried out in May 2024 in the *Laboratory and Process Skills 1* module taken by students in Year 1 Semester 1. Students participated in a Water Filter Challenge, which intentionally incorporated designed failures such as blocked filters and turbidity issues, to encourage iterative redesign and reflective thinking. Both observations followed a structured template focusing on intentional failure design, student reactions to failure, instructor questioning techniques and collaborative problem-solving behaviours.

- **Student written reflections** were collected in January 2024 from the same cohort of Year 2 students. Each student responded to guided reflection questions embedded in their coursework assessment, addressing causes of failure, lessons learned and possible improvements. The reflections were analysed thematically to identify recurring themes such as recognition of failure as feedback, emotional resilience, team dynamics and safety-oriented thinking. These insights complemented the observation and FGD data, providing individual perspectives on learning from failure.

All qualitative data were coded and analysed using a thematic approach. Emerging themes from classroom observations and reflection responses were compared with focus group transcripts to ensure consistency and enhance validity through data triangulation. The combined analysis of quantitative (SFT and KAI) and qualitative findings enabled a comprehensive understanding of how students' tolerance for failure, creativity and resilience evolved over the course of the program.

RESULTS AND DISCUSSION

This section presents the data analysed from the SFT and KAI surveys and it is supported by qualitative data that were collected through the FGD with students. In the data analysis, the attributes of failure tolerance, resilience and confidence were grouped together due to their conceptual relatedness and these attributes reflect a shared dimension of personal adaptability and emotional strength. Meanwhile, creativity and innovation were examined in contrast to conformance to norm because there could be a potential tension between fostering originality and adhering to established standards, which may be particularly relevant in chemical engineering that balances safety, precision and innovation. Understanding these groupings would enable the authors to better support student growth by recognising how these traits interact and manifest within the chemical engineering program.

Failure tolerance, resilience and confidence

Data were compared at the 3-point measurements within an academic year as shown in Figure 3. Overall for the entire academic year, students' failure tolerance (1.39 to 1.57) and resilience (3.26 to 3.36) increased as expected because the chemical engineering program was designed to cultivate this attribute. The program's structure and challenges were aimed at fostering students' ability to adapt, persist, and recover from setbacks, aligning with its educational objective to build resilience and prepare its graduates for the workforce. It is worth noting that although the students' confidence remained the same when measured at start and end of the academic year, their confidence was observed to increase for the first half of the academic year and then decline to its initial level.

DCHE adopted the spiral curriculum model in 2018 (Yang et al, 2021) and its Year 1 modules primarily emphasised knowledge acquisition and comprehension-based learning outcomes, with minimal focus on application. In Year 2, the emphasis shifts toward higher-order application outcomes, supported by fewer knowledge-based learning outcomes, thereby increasing the complexity of learning. Consequently, students often find Year 1 modules relatively easy to master and they score good grades, which enhances their confidence. However, as they progress to Year 2, they encounter more challenging tasks due to advanced learning outcomes and elevated expectations. Entering Year 2 with high confidence, students face a steeper learning curve, and some challenges may have diminished their confidence as the pace and complexity exceeded their initial ability to adapt and thrive.

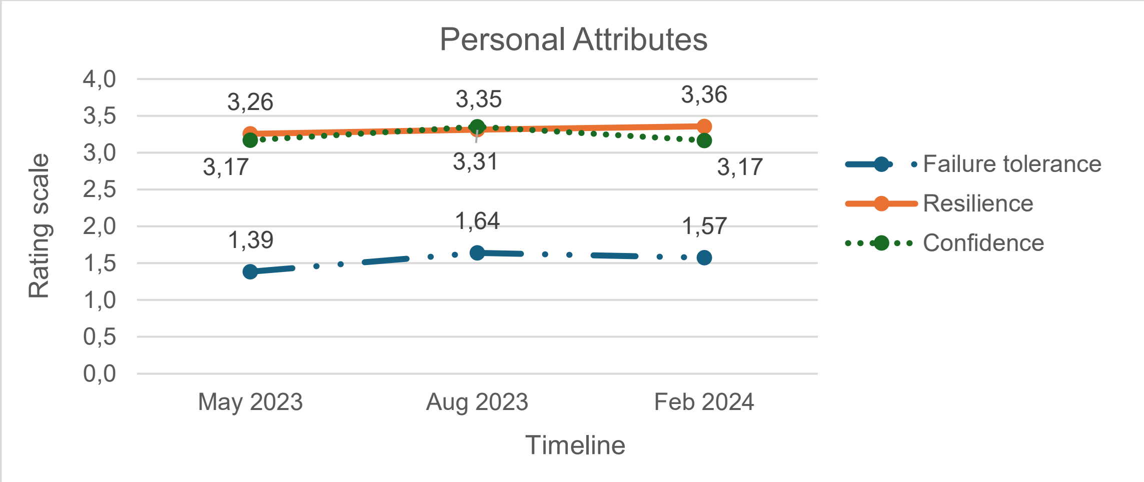

Figure 3. Rating on personal attributes

The failure tolerance (1.39 to 1.64), confidence (3.17 to 3.35) and resilience (3.26 to 3.31) followed an upward trend during the first half of the academic year. However, a notable decline in failure tolerance (1.64 to 1.57) and confidence (3.35 to 3.17) was observed in the second half, diverging from the continued growth in resilience. This pattern may be attributed to the increasing complexity of concepts and contexts introduced in Year 2 Semester 2 of the DCHE program. As students are required to engage with higher-order thinking skills and apply knowledge in real-world problem-solving, the cognitive and emotional challenges may have impacted their perceived confidence and tolerance for failure.

In general, students rated their failure tolerance (below 2.0) lower than the level of resilience and confidence (above 3.0) as shown in Figure 3. Students showed higher resilience and confidence because they seemed to have the ability to succeed and able to bounce back from setbacks but not necessarily from academic failure due to concerns of grading and peer pressure that failure leads to embarrassment. At the focus group discussion, one student shared that "*he often kept trying despite feeling frustrated and this is mainly driven by assessments and grades, having an ownership over the project and the desire to improve based on feedback*".

Another student shared that "*he does not want to fail because he is compared with his peers*." This seemed to suggest that students fear failure because it feels like a judgement rather than a learning opportunity, thus, having lower tolerance to failure.

In Year 2 Semester 1, students were introduced to the Chemical Product Design pathway for the first time within the DCHE program. This initial exposure provided a foundation for students to gradually develop their tolerance for failure, resilience and confidence, as reflected in the t-test results in Table 1 that compares the p-values for Semester 1, Semester 2 and for the entire academic year. According to constructivist learning theory (Piaget, 1976), students build knowledge through active engagement and reflection on experiences, including failures and errors. The iterative nature of design tasks in Semester 1 likely facilitated this process, allowing students to learn from failure and adjust their strategies accordingly. Repeated exposure to failure helps develop cognitive flexibility where students develop the ability to shift thinking and adapt to new information, thereby increasing the level of resilience and confidence. Within the learning environment, students were guided by their lecturers to learn from experience and see failure as part of growth. This could then support students to build a foundation for these attributes. One student shared that "*the lecturer is the pillar of support who provide support and understand his struggle as a student*."

This dynamic was clearly demonstrated in the Laboratory and Process Skills class in May 2024 where Year 1 students were engaged in a "Water Filter Challenge". The instructors intentionally designed multiple failure points, such as incomplete water flow or unchanged turbidity, to trigger productive iteration. Instead of offering direct solutions, instructors posed probing questions like "*why 100 grams of sand?*" or "*why did the water not flow through?*". Students were prompted to reflect using a plan-do-check-act framework and document possible causes of failure as part of graded reflection. Through repeated testing and redesign, students' confidence and resilience visibly improved, embodying the "fail fast, fail early" ethos while meeting the CDIO learning outcomes.

Reflection responses revealed that many students viewed failure as a necessary but emotionally challenging part of the learning process. Several responses expressed frustration such as "*It was tiring but we learnt from mistakes.*" while others highlighted the value of iteration such as "*We improved after testing again.*" These reflections reinforced the quantitative findings that resilience increased even when confidence fluctuated.

Having gained experience from encountering and learning through failure, students entered Semester 2 with a certain level of failure tolerance, resilience and confidence. The data in Table 1 indicated that students' attitude toward failure and their resilience remained consistent throughout Semester 2 but their confidence level decreased.

Table 1. t-test outcome for failure tolerance, resilience and confidence

Data collection period	p-value (at 5% significance level)			t-test Outcome
	Failure tolerance	Resilience	Confidence	
Semester 1 (May – August 2023)	0.0000014	0.010	0.0003	Students become ***more*** tolerant to failure, resilient and confidence from start to end of Semester 1
Semester 2 (August 2023 – February 2024)	0.1318	0.122	0.0006	There is ***no change*** in students' tolerance to failure and resilience, but students become ***less*** confident from start to end of Semester 2
Full academic year (May 2023 – February 2024)	0.0014	0.015	0.4742	Students become ***more*** tolerant to failure and resilient but confidence remained the ***same*** from start to end of academic year

When the foundation is established in Semester 1 where students had accumulated prior experiences and entered Semester 2 with a more sanguine attitude toward failure. This is an indication that students become better equipped to handle failures with a consistent level of emotional strength and problem-solving capacity. This aligns with Bandura's social cognitive theory (Bandura, 1982), particularly the concept of self-efficacy, which suggests that repeated mastery experiences, including overcoming failure, contribute to students' failure tolerance and resilience. Self-efficacy refers to an individual's belief in their ability to succeed in specific situations. So, students would be less likely to be overwhelmed by subsequent failures and more likely to approach challenges with a mindset of persistence, adaptability and self-efficacy.

When examining the attributes across the entire academic year, the findings suggest a gradual developmental trajectory: students became increasingly tolerant to failure, building resilience while maintaining the same level of confidence from beginning to the end of the academic year. This progression supports the idea that learning from failure is a critical component of active and experiential learning, where reflection on concrete experiences leads to deeper learning and personal growth. One student shared that "*the reflection journal helped him with learning and learning from mistakes helps him understand better*." Through Reflection Journals, students analysed what went wrong and they could uncover possibilities that fuel creative breakthroughs. Additionally, responses elicited from the FGDs showed that students had both intrinsic and extrinsic motivations to continue despite 'failing': they wanted to learn from the experience, they wanted to see the end product due to the time and effort spent working on it, and that their grades will be affected if the work is incomplete.

In such active and experiential learning environments, students are not passive recipients of information; rather, they engage directly with the problems and situations. They make decisions and experience the consequences of those decisions. When failure occurs, it serves as a critical learning opportunity, prompting students to analyse and reflect underlying causes, adjust their strategies and apply knowledge and skills in novel ways. This iterative process reinforces understanding through practice and fosters deeper cognitive engagement.

Creativity vs Conformance

The DCHE program effectively cultivates students' ability to conform to established norms, as evidenced by an increase in the conformity scores from the beginning to the end of the academic year as shown in Figure 4. In contrast, the Chemical Product Design pathway fostered creativity and innovation during the first semester, however, a noticeable decline in these attributes was observed in the second semester. This decline may be attributed to the increasing emphasis on conformity within the broader curriculum, which potentially suppressed the development of creative thinking.

Classroom observation during the *Chemical Product Design and Development* module in January 2024 further illustrated this tension. Students were observed meticulously following online tutorials and safety guidelines to ensure correct wiring and 3D printing connections. While such practices reinforced procedural accuracy and reduced risks, they also reflected a "single-correct-answer" mindset, leaving limited room for creative experimentation. The instructor acted primarily as a facilitator, encouraging students to self-correct through trial-and-error. This environment tended to favour adaptive over innovative problem-solving, aligning with the quantitative finding that students became more conforming rather than inventive toward Semester 2.

Analysis of students' written reflections further supported the observation that safety and correctness were dominant design priorities. Many responses emphasised avoiding errors such as "*We followed the right steps to prevent accidents*" and ensuring precision such as "*There is only one right way to make it safe*." Such language illustrates the prevalence of adaptive rather than innovative mindsets, consistent with the observed rise in conformity scores during Semester 2.

Figure 4. Rating on creativity & conformance

The t-test results shown in Table 2 further confirmed that students indeed become more conforming to norm from start to end of the academic year at 5% significance level, while creativity and innovativeness students remained stable. This could be attributed to the chemical engineering program that traditionally develops systematic problem solving, strict adherence to standard operating procedures and safety practices as well as application of established engineering principles. This structured approach cultivates analytical thinking and technical precision. One student shared that "*process operation skills training emphasised safe operation to prevent incidents and accidents because failure in a chemical plant has negative consequences*." In contrast, chemical product design requires students to engage in creative thinking, innovation and open-ended exploration, which the competencies differ significantly from those emphasised in core chemical engineering training. This contrast creates a pedagogical dichotomy within the curriculum that students must learn to navigate. Consequently, when students encounter failure in creative or design-based tasks, it may have conflicted with their dominant mindset of 'cannot fail' because failure is perceived as unacceptable in the chemical engineering workplace, leading to confusion and a decline in self-confidence as indicated in Table 1.

Table 2. t-test outcome for creativity and conformance

Data collection period	p-value (at 5% significance level)		t-test outcome
	Creativity and innovation	Conformance to norm	
Semester 1 (May – August 2023)	0.0009	0.0118	Students become ***more*** creative and innovative and conforming to norm from start to end of Semester 1
Semester 2 (August 2023 – February 2024)	0.1335	0.0713	There is ***no change*** in students' creativity and innovativeness and conformance to norm from start to end of Semester 2
Full academic year (May 2023 – February 2024)	0.0532	0.0004	There is ***no change*** in students' creativity and innovativeness but student become ***more*** conforming to norm from start to end of academic year

When failure is normalised and not punished through grades, students may become more willing to take risks. This openness to experimentation is crucial in developing creativity and innovativeness. One student shared that "*he faced many challenges during the prototyping phase and it is good learning opportunity*". The first exposure serves as a foundational phase where students begin to internalise the value of learning through trial and error. These experiences align with CDIO Standard 5 Design-Implement Experiences that enable cognitive development through assimilation and accommodation of new experiences through learning from failure.

In conclusion, when students encounter repeated failures at the different stages within their learning environment, they gradually become accustomed to the experience and develop resilience and tolerance for setbacks. This process not only strengthens their ability to cope with challenges and failures but also fosters higher levels of creativity and innovation. Equipped with these attributes, students grow in confidence while maintaining an awareness that conformity to established norms remain an essential trait within the chemical engineering industry.

LIMITATIONS AND RECOMMENDATIONS

This study has several limitations that should be considered when interpreting the findings. First, the response rate for each survey varied because participation was voluntary. This may have introduced the possibility of non-response bias, as individuals who chose to participate may differ systematically from those who did not, potentially affecting the representativeness of the results. More targeted follow-ups with students or incentives through using testimonial of participation could be employed to improve response rates.

Second, the findings presented are indicative rather than definitive. While the data provide useful insights, they should not be interpreted as conclusive evidence. Further research with larger and more diverse samples, as well as longitudinal designs, is warranted to validate and extend these observations.

Third, both the SFT and KAI instruments rely on self-reported ratings. Self-assessment measures can be influenced by cognitive biases, including the Dunning–Kruger effect, where individuals with lower ability may overestimate their competence while those with higher ability may underestimate theirs. This bias could impact the accuracy of the reported scores and, consequently, the interpretation of the results.

As students encounter and overcome failure during the first semester, they build confidence in their problem-solving abilities. However, despite developing technical competence, students may still experience emotional distress following failure because they have not fully developed the emotional tools to process failure constructively. So, the lecturer would need to play a pivotal role to shift students' focus from "what went wrong" to recognising and reflecting on "what went right". Consider striking a balance between using graded assessment and ungraded formative feedback to help the student to gain confidence through learning from mistakes. Such reframing can support the development of a stronger sense of agency and competence, fostering more confident and adaptive students.

Providing psychological safety for students to fail and learn from their mistakes would create a fail-safe environment for students to "fail fast, fail early". Such an environment not only facilitates active and experiential learning but also encourages the development of creativity and innovation by reducing the fear of failure.

Observations from both Year 1 and 2 classes reaffirm that creating psychologically safe, scaffolded environments, where students are guided on coping with failure early as observed during the Water Filter Challenge and gradually encounter structured constraints later such as those prototyping activities, can balance resilience-building with technical accuracy. Such progression may help students transit from 'fear of failure' to 'confidence through competence'.

Across the reflections collected in January 2024, three recurring themes emerged: (1) recognition of failure as feedback, (2) increased appreciation of teamwork and communication, and (3) awareness of constraints such as safety and time. These reflections demonstrate how students internalised the CDIO learning outcomes, particularly Attitudes, Thoughts and Learning (CDIO Syllabus Section 2.4), through structured reflection after experiencing failure.

A key factor that warrants deeper study is how DCHE students entertain the notion of learning from failure in product design vs non-tolerance of failure in chemical plant operations where students had to 'code switch' from product design to process operation when they attend the respective lessons. Future work could also investigate whether students could become more conforming and more creative at the same time and devise relevant teaching strategies to support students in making sense of their experiences and adopting the desired attributes referencing the approach proposed by Cheah & Willems (2025).

CONCLUSION

This study highlighted the role of chemical product design in developing students' tolerance for failure and the development of resilience. With reference to the first research question, the process of coping with failure not only strengthens students' problem-solving confidence but also supports sustained creativity and innovation. Resilient students are more likely to persist through failure or challenges and continue refining their ideas and excel. However, the strong emphasis on conformity within the broader chemical engineering program may have inhibited the growth of creative thinking and this addresses the second research question. This tension reflects prevailing industry expectations, where engineers are typically not required to exercise creativity in routine operations, particularly in the context where consistent and operational safety are of utmost importance.

In the context of the modern workplace, graduates require a more divergent set of skills and competencies. Some of these attributes such as creativity, adaptability and adherence to standards may exist in tension with one another, necessitating innovative approaches to curriculum design. Learning from failure is observed in this study to enhance active and experiential learning, enabling students to develop resilience, problem-solving abilities and creative thinking. So, the CDIO Framework can be used as a lens for program assessment, to systematically evaluate and improve educational strategies, allowing standard-by-standard analysis to identify areas for enhancement using the 'learning from failure' approach while ensuring alignment with industry needs.

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BIOGRAPHICAL INFORMATION

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