EMBRACING FAILURE AS AN INTEGRAL ASPECT OF ENGINEERING EDUCATION

Markéta Foley

Reykjavík, Iceland

Joseph Timothy Foley, Marcel Kyas

School of Technology, Reykjavík University, Reykjavík, Iceland

ABSTRACT

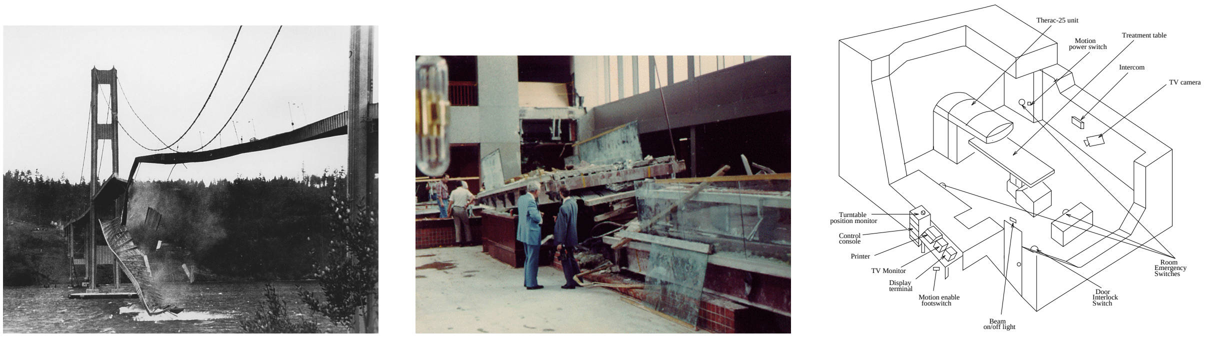
In Engineering education, failure is generally considered unacceptable: catastrophic failures are typical horror stories relayed to students. This attitude is pervasive enough that many students become unwilling to explore creative ideas, or they may make seemingly unreasonable design decisions driven by their fear of failure. Students choose to remain in the space of Vincenti's "normal design" where they know the operational principles and can manage all risks. They avoid the innovation space of "radical design" for fear of an unacceptable result and lack of guidance from teachers about how to navigate such high risk spaces. We believe that experiencing failure in a safe environment is a necessary part of transformative learning in line with the intentions of CDIO. Opportunities to explore tangents that may result in seeming failure need to be built into the curriculum, else the possibilities for creativity and discovery are reduced. The concept of what failure means and the value derived from it need to be examined. A safe space for failures must be created within the Engineering classroom for students to discover their innate courage to explore, innovate, and create. We propose specific methods for fostering such an environment, including implementing version control and documentation of project milestones, a non-hierarchical classroom environment, Non-Violent Communication, and self-designed success criteria.

KEYWORDS

failure, non-hierarchical classroom, transformative learning, radical design, fear, non-violent communication, Standards 4,5,6,7,8

INTRODUCTION

Failure is used as a teaching example in many fields (Figure 1). In dynamics, we consider the collapse of the Tacoma Narrows bridge (von Kármán, 2005). In mechatronics and software engineering, echos of the deadly Therac-25 still cause shudders (Leveson, 1995). The classic structural textbook "To engineer is human: the role of failure in successful design" by Petroski describes the deadly collapse of Pemberton Mill in 1860 (Petroski, 1992). In more modern days, the Hyatt Regency Hotel in 1981 had a walkway collapse, killing many and changing how



(a) Tacoma Narrows Bridge Collapse (Encyclopaedia Britannica, 1940)

(b) Hyatt Regency collapse floor view (Lowery, 1981)

(c) Therac-25 instrumentation layout (Leveson, 1995)

Figure 1. Examples of disasterous classical engineering failures often presented to students.

civil engineers design buildings (Marshall et al., 1982).

The commonality of attitude towards failure in these cases is that it needs to be avoided in order not to suffer the negative consequences. A belief is clung to that by avoiding failure at all costs and at every step along the way (including during the educational process), we can prevent such tragedies altogether.

However, this desperate clinging to avoiding failure has a serious downside: lessened understanding of the inner workings of a system and how to debug errors. In addition, it is an unrealistic ideal; with a long enough view, all components and systems will eventually experience failure. The question to ask is therefore not “Will it fail?”, but rather “When will it fail and how?”

Rather than closing off from failure altogether and clinging to an unrealistic ideal, would it not serve us better to acknowledge failure’s existence as well as the existence of our own fear about it? Is it not crucial to openly examine our attitudes towards failure together with our students, the future engineers who will build the bridges and design the next medical products? By knowing failure better, we can modify our designs and make adjustments to the use and lifetime of our products, which may ultimately result in fewer tragic consequences.

To address the limited thinking around failure, we propose here a shift in academic Engineering education. An educational system built on an attitude of failure avoidance produces students unwilling to take risks and explore new ideas as fully as they might otherwise. Their creative process is limited by the fear of failure and its consequences (ex. low grades, judgment from fellow classmates and/or teachers), and possibilities for discovery and innovation are reduced.

By acknowledging the presence of fear in the Engineering student, we naturally move away from the more traditional model of education as the mere passing down of information from teacher to student. We turn in its place to models that embrace the wholeness of the student (and the teacher) and allow learning to take place on many different levels of the human experience. In particular, we draw here from the ideas of Transformative Learning Theory (Cranton, 2016; Slavich & Zimbardo, 2012), applying some of its principles to create a safe space for Engineering students to explore their creative ideas without being punished or judged for failures.

This paradigm shift will not happen without us, the teachers, playing by the same rules and finding the courage within our own selves to stand in the presence of fear. For the author's own journey, we drew inspiration from Parker Palmer's ideas in "The Courage to Teach" (Palmer, 1998) and the words of Mahatma Gandhi from 1913:

> "If we could change ourselves, the tendencies in the world would also change. As a man changes his own nature, so does the attitude of the world change towards him... We need not wait to see what others do." (Gandhi, 1964, p. 158)

Accepting the invitation to begin with our own selves in order to create the change we wish to see mirrored in the world, we set off on an exploration of questions such as: How does fear show up for us as teachers? Where are the places that require us to step outside of our comfort zone and how do we respond when we find them? Where might we ourselves encounter failure and can we open to that possibility? What does it even mean to fail?

As teachers, we guide the way for our students. And as authors of this position paper, we do the same by allowing ourselves to step outside of the comfort zone of the traditional model of Engineering education and be inspired by the experience of teachers in non-academic environments, most notably yoga. We share here ideas learned from our explorations in other territories and propose ways they can be incorporated into Engineering education within the walls of academic institutions. Ideas such as holding space, anchoring, and Non-Violent Communication (Rosenberg, 2015) are joined with concepts of non-hierarchical classrooms and documentation to create safety checkpoints. All this in service of creating a safe space for Engineering students to discover their innate courage to explore, innovate, and create, a goal explicitly stated in the CDIO standard (CDIO, 2020, Standards 6–7).

RADICAL DESIGN AND DEFINITION OF FAILURE

Before defining failure, let us consider Walter Vincenti's two modes of engineering. The first is "normal design", described by Vincenti as: "The engineer [. . .] knows at the outset how the device in question works, what are its customary features, and that, if properly designed along such lines, it has a good likelihood of accomplishing the desired task." (Vincenti, 1993, p. 7)

The second is "radical design", which Vincenti defines as: "How the device should be arranged or even how it works is largely unknown. The designer has never seen such a device before and has no presumption of success. The problem is to design something that will function well enough to warrant further development." (Vincenti, 1993, p. 8) Radical design is the space for significant innovation.

A teacher can only share what they know. In the traditional top-down educational model, the student only comes into a direct relationship with the teacher, not the object being studied. Thus, it is not surprising that education focuses mainly on normal design. The students study existing designs, learning the operational principles of devices and their customary features. How could they study what the teacher can only imagine?

Furthermore, normal processes are easy to grade and evaluate because we measure similarity to existing, tested solutions. Processes without clear metrics or definitions of success are much more time-consuming and subjective to evaluate. How would one even generate a rubric?

In the section ‘Non-hierarchical Classroom”, we address some of these questions and share an alternative to the top-down education model. The student does come into a direct relationship with the subject of study and can therefore derive knowledge about it independently of what the teacher herself knows. Under this model, radical design becomes a real possibility.

Let us now turn to definitions of failure itself, and examine them in light of normal and radical design. Suh’s complexity theory considers failure a critical point in developing a quantification of unrobustness he defines as Information content (I). An optimally designed system’s Information content (I_{sys}) would be: (Equation 1)

$$I_{sys} = \sum I_i = -\sum_i \log_2 p_i \tag{1}$$

where p_i is the probability of meeting Functional Requirement number i given a list of such requirements (Suh, 2005, p. 39). More simply, in an optimally designed system, the Information content (chance of it failing) is dependent on the probability of each required function being met. The desirable situation is to minimize Information content, which Axiomatic Design calls the “Information Axiom”.

In the context of normal vs. radical design, we observe that the Information content of a system is only known after its probabilities of success are measured. If we want to maximize success, i.e. minimize Information content, we choose designs with *high probability* of meeting Functional Requirements. How do we accomplish this? We choose what has worked in the past (i.e. normal design).

With radical design, we lack the required information. Our probability of meeting Functional Requirement i is very low, if not 0. We lack the experience to expect to meet the requirement because nothing similar exists. Our design thus has a large, if not infinite, information content. The main experience of radical design is failing, addressing the failure, and improving the design iteratively.

To students, failure has different meanings still. In project-based courses, failure may mean that the device they built does not do what it was required to do, what they might like it to do (or think it “should” do). Failure may also mean simply getting an undesirable grade in a course. This grade may have negative consequences such as having to retake the course, delayed graduation, and possibly loss of scholarships or loans. The theme here is that the failure of a design reflects poorly on the student’s perceived ability. Therefore, is it so surprising that students are unwilling to be daring, step into the realm of radical design, and innovate? We hold here that a change in perspective on the part of teachers and academic institutions is called for. If we wish to encourage students to dare to innovate, we must not judge or shame them for failures they may encounter. We must detach the failure of the design from the ability/personality of the student herself, embracing failure as an opportunity to learn.

THE SECI CYCLE OF KNOWLEDGE CREATION

Gilbert Ryle distinguished two kinds of knowledge: “knowing that” and “knowing how” (Ryle, 1949) to differentiate between verbalized intellectual activities and their applications. Traditional education systems focus on “knowing that”, which is easy to test. There is less focus on teaching “knowing how”. Evaluating “knowing how” is challenging. Students must explain and justify their processes and decisions. “Knowing how” is *tacit knowledge*, a knowledge that we cannot verbalize easily. A classic example is riding a bike. We learn how to ride a bike, but when we are tasked with *explaining* to somebody how to ride a bike, we can only say: “practice”. One does not learn to ride a bike by reading physics textbooks. One learns by riding the bike, failing, and trying again. Michael Polanyi formalized this tacit knowing by observing “We know more than we can say.” (Polanyi, 1958, p. 4)

Polyani argues that we do not learn many skills through formal processes. Tacit knowing is a product of life experience. How do we transfer such knowledge acquisition to Engineering classrooms? Our students will not even mount the proverbial bike for fear of failing.

Nonaka and Takeuchi see tacit knowledge as a strength of the East-Asian way of thinking:

> “Japanese companies, however, have a very different understanding of knowledge. They recognize that the knowledge expressed in words and numbers represents only the tip of the iceberg. They view knowledge as being primarily “tacit”–something not easily visible and expressible. Tacit knowledge is highly personal and hard to formalize, making it difficult to communicate or share with others. Subjective insights, intuitions, and hunches fall into this category of knowledge. Furthermore, tacit knowledge is deeply rooted in an individual’s action and experience and the ideals, values, or emotions they embrace.” (Nonaka & Takeuchi, 1995, p. 8)

An important dimension of tacit knowledge to engineers is skills such as choosing a particular design or estimating the probability of the design’s success.

Nonaka and Takeuchi observe four distinct processes in knowledge creation: Socialization, Externalization, Combination, and Internalization (SECI cycle). Their model proposes ways to transform the individuals’ knowledge into an institution’s knowledge, allow an institution to expand on it, and teach this knowledge to new individuals. In the CDIO context, the institutions are the universities and the *community* of engineers and researchers, and the individuals are the students, teachers, engineers, and researchers.

Socialization refers to informally transferring tacit knowledge. For example, in a master/apprentice relationship, the apprentice will follow the master’s instructions or observe the master. These activities result in the apprentice learning what the master expects. *Externalization* refers to codifying tacit knowledge, for example, by writing instruction manuals. The purpose is to preserve an individual’s knowledge in the institution and archive it. *Combination* generates new knowledge by combining externalized knowledge. Exchanging information through documents, systemizing it, storing it in databases, and reconfiguring it are examples of knowledge combination. Nonaka and Takeuchi (1995, p. 67) observe that: “Knowledge creation carried out in formal education, and training at schools usually takes this form. An MBA education is one of the best examples of this kind." *Internalization* is assimilating externalized and combined knowledge into the learner's tacit knowledge. It is closely related to "learning by doing". The learner performs instructions from a manual, often guided by a teacher, and learns how to practice this knowledge. They may reexperience other people's experiences by reading the material or performing the instructions.

Consequently, we learn "knowing how" primarily through socialization, a process employed in teaching situations outside the academic environment (such as in yoga and martial arts studios). Typically, a teacher or master demonstrates the activity, and the learner imitates it. The teacher may offer corrections, enquiries or specific points to focus on. Alternatively, learners create knowledge in group work. They propose, discuss, try, and evaluate methods in classes, workshops, or projects.

In contrast, most teaching at the university level focuses on combination and internalization: knowledge is passed through lectures and derived from textbooks. Universities teach very little about "how to learn from failure", and "how to view failure as opportunity". Because the consequence of failure is often a low grade, students typically experience failing negatively. They do not reflect on the reasons for failure or develop skills to avoid failures in the future. They will not learn to gauge success probabilities.

To make successful learning of such skills possible, the teacher's role as we understand it needs to change. The teacher must create space for learning through socialization. Our proposal of "Non-hierarchical classroom" below is one way such space can be created. Through witnessing the teacher make room for failing in such a classroom, facilitate reflection on failures, and value the externalization of failures of radical design choices as highly as the ones of success, students may — little by little — be willing to stand in the presence of fear of failure and begin to make different choices.

TRANSFORMATIVE LEARNING AND TRANSFORMATIVE TEACHING

Transformative learning is a theory formulated by Jack Mezirow in the late 20th century (Mezirow, 2012). The theory presents an alternative to the traditional view of education as mere means of acquisition of knowledge delivered by a figure of authority. Instead, it offers that true learning takes place when meaning is made out of a lived experience by comparing it to a past set of assumptions (called "frames of reference" by Mezirow), questioning and adjusting these assumptions to integrate the experience into the wholeness of the self. This leads to a process of transformation at the inner self-level and may show up as shifts in thoughts, emotions, speech, and actions. Sometimes, the transformation is apparent immediately. At other times, it may not happen until years or decades later after the learning experience had planted the initial seeds.

We extend the idea of transformative learning to include transformative teaching, which we define as teaching from a place where the teacher shows up as her whole self in the classroom and, just like the student, opens herself to the possibility of transformative change through the experience (Palmer, 1998, Chapter I – II), (Cranton, 2016, Chapter 10). We offer that by subjecting herself to the same process she invites her students into, the teacher takes the first (and perhaps most important) step towards creating a space within which the students can set out on their own explorations.

CREATING A SAFE SPACE THAT FOSTERS EXPLORATION

With the introduction of the idea of transformative learning and teaching, we have illuminated the gateway to a different model of student-teacher interaction, a stepping stone from which the Engineering student may be willing to take a step into unfamiliar territory despite any fear of failure. In the remainder of this paper, we present specific areas of focus and offer examples of practical tools for the teacher to create and hold safe the space for the student's explorations.

Non-hierarchical Classroom

In “The Courage to Teach”, Parker Palmer offers a visual representation of two models of the classroom (Palmer, 1998, Chapter IV). The first is an objectivist model, consistent with the traditional model of top-down education. Here, the object of knowledge resides at the top. The object is examined by experts (teachers) and knowledge derived from the experts' examinations is passed on to amateurs (students). The flow of knowledge takes place in one direction only, with barriers in place to prevent any backflow that may contaminate the object of knowledge with subjective experiences. The student never comes in direct relationship with the object of knowledge itself; it is accessed only through the teacher as the figure of authority.

Palmer calls this model the “objectivist myth” and goes on to offer an alternative, which he calls the “community of truth”. This is a fluid model where teachers and students alike gather in a community (as “knowers”) around a subject of common interest. This model offers a direct pathway for each student to come into a relationship with the subject as well as with the teacher and other students. The flow pattern of knowing and learning is in all directions.

Palmer's definition of teaching as “the creation of space in which the community of truth is practiced” (Palmer, 1998, p. 90) aligns well with our thesis of creating a safe space for the Engineering student to explore within, daring to follow interesting tangents with the intention of knowing the subject of common interest. By virtue of creating a community, space for such excursions from the “home base” is held not only by the teacher, but collectively by the entire community. At times, the explorations may lead to fascinating discoveries that enrich the experience of all members of the community. At other times, they may end in what we might term “failures”. Here, the community functions as an anchor line, helping to bring each member back to “home base”.

A question that offers itself for contemplation with Palmer's model of the “community of truth” is in regards to the role of the teacher. Parker's quote would imply that the main role of the teacher is to create the space for the practice of this model of learning. We can translate this as designing a course in such a way that brings the students in direct contact with each other, the teacher, and the subject of common interest. Some practical ideas may include creating opportunities for dialogue and discussion (in small groups of students alone as well as with the teacher), giving and receiving frequent feedback (both from teacher to students and from students to teacher and to other students), participating in goal-setting and evaluation (of self and others), designing physical spaces in ways that represent the model itself (for example, with the teacher seated in a circle amongst the students rather than standing in the front on a podium). For our topic of fear of failure, in particular, the teacher may offer their own experience with fear and share stories of their own failures, to normalize the experience for the students. The need for these interactive elements is described in CDIO Standard 8 Active Learning.

A crucial part of creating a safe space for the students' explorations is the design of appropriate boundaries. The space must be open enough to allow freedom to explore, yet bounded enough to maintain focus on the subject of common interest and to ensure safety. If our intention is to allow for failures to be experienced, it is our responsibility as teachers to ensure (within our best abilities) that the student and their classmates remain safe — physically, mentally, emotionally — throughout their explorations. In the same way that we would not let a 3-year-old child loose to explore the kitchen knowing that the knife drawer is within their reach, we bound the teaching space appropriately so as to prevent the re-occurrence of scenarios such as the Stanford Prison Experiment (Zimbardo, Maslach, & Haney, 2000).

Once an appropriately bounded space has been created, the teacher's role turns to the maintenance of this space: making modifications as needed to respond to the course's unfolding and holding space for the students' experiences within the boundaries of the course. In the best possible scenario, the teacher becomes a mentor to the student for the duration of the course or even beyond.

We conclude this section of our paper by sharing a description of the role of a mentor from Donna Farhi. Farhi's quote captures within it many of the ideas explored in this paper: holding space for the student and any fear that may show up for them, Parker's model of teachers and students gathering in community around truth, and the process of tacit knowledge creation through internalization:

> "A mentor assists the birthing of the student's dreams, visions, and hopes, and most important, what the student has not yet dared to imagine... A true mentor does not cultivate the student's dependence on her insight but facilitates the student's trust in his own inner promptings. This is the beginning of independence and true freedom." (Farhi, 2006, p. 16)

Non-Violent Communication

Non-Violent Communication (NVC) is an approach developed by the clinical psychologist Marshall Rosenberg (Rosenberg, 2015). The method is built on the principle of non-violence — not causing harm to oneself or others — and is employed in a wide range of disciplines including healthcare, parenting, yoga, business settings, and education (Lasater & Lasater, 2009), (Rosenberg, 2005).

We bring in NVC as a technique to create and maintain the safe space for the students' explorations previously discussed. NVC offers an alternative to the very common form of communication involving asserting one's power over other people or situations. It replaces this with respect and choice. To offer an example, reflect whether you have ever tried to will a tight muscle to release its tension or verbally force a toddler to go to sleep. If you have, you may have experienced that trying to assert your power and impose your will in this way does not yield the desired results. No amount of forceful words, threats, shaming, or punishment will result in the muscle relaxing or the toddler drifting peacefully off to sleep. The muscle remains tense, the toddler remains awake, and the situation may go on to escalate.

The same principles hold true in the teacher's communication with students. Attempting to force students into doing something — be it speaking up in class or setting off to explore some unknown territory they are uncomfortable with — will most likely result in similar resistance. Direct conflict may or may not arise, but either way, the student and teacher are locked in a battle of wills.

Through the practice of NVC, we have the opportunity to experience a different outcome. Non-violent, permissive language that encourages inquiry may create that sense of safety in the student that enables him or her to venture beyond the boundaries of fear. Such language lets the student know that they have a choice in how far they venture, that they can turn back at any time and will not be judged for it, that they may encounter failure and will not be punished for it (through, for example, receiving a low grade). NVC helps to foster a safe environment within which to explore and begins to unravel the patterns of fear within the student, allowing him to walk down creative avenues that may turn out to be dead-ends and safely return from such explorations.

Building Safety Checkpoints into the Curriculum with Documentation and Version Control

In the previous discussion, we had raised the idea of the community acting as an anchor line to bring any member back from failed expeditions. We extend now the idea of anchors to include creating “safety checkpoints” along the way, something to return to if failure is encountered in the process of creative exploration.

Fear can often be the emotion that grips a student as they consider investigating a “risky” endeavor. This can be adding a new feature to a CAD drawing or reworking an existing part of the software. If the idea does not work out, the entire system may become nonfunctional. What is effectively needed is some sort of “time-machine” so that investigations that do not pan out do not doom the project altogether. Thankfully, software engineers have been grappling with this exact worry for decades, which has resulted in the concept of version control tools. When one uses Subversion, Git, or other version control tools, the entire history of the files is saved in a manner that can be played back and forth with annotations. For non-software-focused disciplines, this can seem a bit like magic; many of them are used to keeping files with dates in their names to make sure that they can always get back to a previous state. Needless to say, the manual method becomes extremely cumbersome and problematic when a team is working together in a common storage location. Modern version control tools (particularly git) even have a concept of “branching”, allowing development to continue down different paths before merging back up or being abandoned (Chacon & Straub, 2014). The use of this paradigm provides a safety checkpoint whereby a student can feel free to take risks knowing that she can always return to somewhere familiar with minimal effort.

In project design classes following our paradigm, we allow students to choose their difficulty level as part of the project proposal process. During this early planning phase, they must align the risk of failure with the ambition of what they want as an outcome. On the other hand, heavily structured project courses start with a clear set of requirements that the students must develop a working solution to or risk a poor grade. In this situation, the students may choose safer and more conservative approaches, sacrificing innovation for a guarantee of a passing grade. Within the new paradigm, students are given constraints to the possibilities of their projects, but the development of metrics and requirements they must meet is left as an exercise to them.

These requirements and metrics are evaluated as to how realistic they are to the stated goal but otherwise left for the students to manage.

A traditional artifact developed as part of project courses such as Engineering X at RU described in Foley and Vafells (2022) can also provide a measure of safety: documentation. This comes in the traditional format of a final report, which is again, traditionally graded and never examined again. In our "embracing failure" approach, we have techniques to improve the utility of documentation and show the need for iteration. First, students pass in a draft of their report, get feedback and a lower-weighted grade, then are given the chance to review it and add supplementary material. Second, milestone presentations are part of the curricula to remind students to collect data, images, and other relevant information as they proceed. Third, students develop design notebooks to document their progress throughout the project (similar to the method described in Foley (2016)), and the notebooks are regularly assessed with detailed feedback. Finally, the teams create an instructional video and manual before the end of the course to demonstrate the functionality of the device at that phase. This video artifact came about due to many projects suddenly malfunctioning the night before the final presentation, resulting in students being unable to demonstrate it with any functionality at all.

CONCLUSION

We hold that the careful design decisions presented in this paper exemplify applying many of the CDIO standards (CDIO, 2020) to create a safe space to experience "failure" in an environment conducive to transformative learning. In Standard 4 (Introduction to Engineering courses), failure must be clearly defined as a methodological issue to be addressed, rather than the outcome of an experiment or prototype. Standard 5 (Design Implement Experiences) describes a "range of engineering activities" that vary in "scope, complexity, and sequence": the use of the word complexity identifies the possibility that outcomes may not match what was expected. Standard 6 (Engineering Learning Workspaces) requires resources to be allocated to entice students to try out their ideas in experiments by being "user-friendly". An interpretation of "user-friendly" might also mean "failure-robust" such as regular documentation of their process as they go along. Standard 7 (Integrated learning spaces) asks institutions to provide such opportunities to grow through hands-on learning and a "personalized learning experience". We describe design courses that have students choose their approach and develop their own requirements to address this. Finally, Standard 8 (Active Learning) desires to engage students by providing a safe environment for "manipulating, analyzing, and applying idea" which is more likely if the students can acknowledge their fear of failure and courses include interactive elements.

A question in the mind of the reader may linger: In embracing failures, are we proposing recklessness? Are we suggesting that the lives lost in tragedies such as the collapse of the Tacoma Narrows Bridge, Pemberton Mill, or the Hyatt Regency Hotel walkway are irrelevant? No, we are not. We are not proposing negligence: letting the students loose without any guidance from us, to fail spectacularly in ways that endanger themselves, their fellow classmates, or anyone else.

What we propose is neither reckless abandon nor a closing down in the face of fear of failure. What we propose is a middle way. A safe, appropriately bounded environment where students may pursue and test creative ideas without fear of punishment or judgment. A place of innovation consistent with Vincenti's definition of "Radical Design" that opens possibilities and creates opportunities. A safe space held by teachers acting as mentors where ideas can be openly shared within a non-hierarchical community gathered together around a common subject of interest.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

This work was partially supported by the Nordic Master in Intelligent Software Systems (Nordic Council of Ministers in 2017 (decision NMP-2016/10169)).

REFERENCES

CDIO. (2020). *CDIO standards 3.0.* Retrieved from http://www.cdio.org/content/cdio-standards-30

Chacon, S., & Straub, B. (2014). *Pro git* (2nd ed.). Apress. Retrieved from https://git-scm.com/book/en/v2

Cranton, P. (2016). *Understanding and promoting transformative learning: a guide to theory and practice* (3rd ed.). Sterling, USA: Stylus Publishing, LLC.

Encyclopaedia Britannica. (1940). *Tacoma Narrows Bridge.* Online. Retrieved from https://www.britannica.com/topic/Tacoma-Narrows-Bridge

Farhi, D. (2006). *Teaching yoga: Exploring the teacher-student relationship* (1st ed.). Berkeley, USA: Rodmell Press.

Foley, J. T. (2016). Evaluating Engineering Notebooks. In *CDIO annual international conference.* Turku, Finland. (June 12–16, Project in Progress)

Foley, J. T., & Vafells, A. (2022). Engineering X: capstone projects employing formalized design methods. In *18th CDIO annual international conference* (p. 1). Reykjavík, Iceland. (June 13–15)

Gandhi, M. (1964). General knowledge about health XXXII: Accidents: Snake-bite. In *The collected works of Mahatma Gandhi* (Vols. 12, April 1, 1913 - December 23, 1914, pp. 156–160). Ahmedabad, India: Navajivan Press. Retrieved from https://gandhiheritageportal.org/the-collected-works-of-mahatma-gandhi

Lasater, J. H., & Lasater, I. K. (2009). *What we say matters: Practicing nonviolent communication.* Boulder, USA: Shambala.

Leveson, N. (1995). Medical Devices: The Therac-25. In *Safeware: System Safety and Computers* (chap. Appendix). Addison-Wesley.

Lowery, L. (1981). *View of the collapsed walkways, during the first day of the investigation of the Hyatt Regency walkway collapse.* Wikimedia. Retrieved from https://commons.wikimedia.org/wiki/File:Hyatt_Regency_collapse_floor_view.PNG (Public Domain)

Marshall, R. D., Pfrang, E. O., Leyendecker, E. V., Woodward, K. A., Reed, R. P., Kasen, M. B., & Shives, T. R. (1982, may). Investigation of the Kansas City Hyatt Regency walkways collapse. *NIST*(NBS BSS 143). Retrieved from https://www.nist.gov/publications/investigation-kansas-city-hyatt-regency-walkways-collapse-nbs-bss-143?pub_id=908286

Mezirow, J. (2012). Learning to think like an adult: Core concepts of transformation theory. In E. W. Taylor & P. Cranton (Eds.), *The handbook of transformative learning: Theory, research, and practice* (pp. 73–95). San Francisco, USA: Jossey-Bass.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford University Press.

Palmer, P. (1998). *The courage to teach*. San Francisco, USA: Jossey-Bass.

Petroski, H. (1992). *To engineer is human: the role of failure in successful design*. New York: Vintage Books. Retrieved from https://archive.org/details/toengineerishuma00petr/page/n7/mode/2up

Polanyi, M. (1958). *Personal knowledge: Towards a post-critical philosophy*. University of Chicago Press.

Rosenberg, M. B. (2005). *Teaching children compassionately: How students and teachers can succeed with mutual understanding*. Encinitas, USA: PuddleDancer Press.

Rosenberg, M. B. (2015). *Nonviolent communication: A language of life* (3rd ed.). Encinitas, USA: PuddleDancer Press.

Ryle, G. (1949). *The concept of mind*. Hutchinson's University Library.

Slavich, G. M., & Zimbardo, P. G. (2012). Transformational teaching: Theoretical underpinnings, basic principles, and core methods. *Educ Psychol Rev.*, *24*(4), 569–608. doi: 10.1007/s10648-012-9199-6

Suh, N. P. (2005). *Complexity*. Oxford University Press.

Vincenti, W. G. (1993). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore and London: The Johns Hopkins University Press.

von Kármán, T. (2005). Collapse of the tacoma Narrows Bridge. *Resonance*, *10*, 97–102.

Zimbardo, P. G., Maslach, C., & Haney, C. (2000). Reflections on the Stanford Prison Experiment: Genesis, transformations, consequences. In T. Blass (Ed.), *Obedience to authority: Current perspectives on the milgram paradigm* (pp. 193–238). Mahwah, USA: Lawrence Erlbaum Associates. Retrieved from http://pdf.prisonexp.org/blass.pdf