Embracing a Fail-Forward Mindset: Enhancing Engineering Innovation through Reflective Failure Journaling

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1. Introduction

In the evolving landscape of engineering education, the imperative to nurture innovation and resilience among budding engineers has never been more critical [1]. As global challenges become more complex and multifaceted, engineering educators are called upon to devise pedagogical strategies that not only impart technical knowledge but also foster the soft skills necessary for students to thrive in unpredictable environments. This study introduces an innovative educational approach employed in the "Innovation Through Making" course at Worcester Polytechnic Institute, designed to cultivate a 'fail-forward learn-fast' mindset among engineering students. By integrating a graded reflective failure journaling into the fabric of the curriculum, we explore the transformative potential of embracing failures as indispensable learning opportunities, thereby enhancing both engineering and entrepreneurial mindset education.

The concept of the Entrepreneurial Mindset (EM) is pivotal to this approach, emphasizing the value of "Exploring a Contrarian View" (Curiosity), "Assessing and Managing Risk" (Connections), and "Persisting and Learning Through Failure" (Creating Value), as defined by the KEEN Framework [2]. Despite the recognized importance of these elements, there is a growing concern over students' increasing fear of failure and their reluctance to take risks. This is compounded by a culture that sometimes promotes academic perfection instead of rich experiences gained from learning through experimentation and failure. This trend significantly undermines students' self-confidence, as it discourages them from engaging in activities that can foster growth and resilience. Addressing this concern, our study investigates the pedagogical impact of promoting a productive failure mindset as a cornerstone for developing EM among students.

The 'fail-forward learn-fast' mindset challenges conventional perceptions of failure, advocating for its recognition as a crucial stepping-stone towards rapid learning, innovation, and personal growth [3]. This mindset is particularly relevant in the iterative nature of engineering problem-solving and innovation, where each setback can serve as a pivot towards refinement and success. Through an in-depth examination of students' interactions with Failure Journals within multidisciplinary teams over two offerings of 8-week course across two years, our research aims to share the pedagogical benefits and insights derived from this innovative approach.

The reflective 'Failure Journal' component of the curriculum encourages students to document, reflect upon, and learn from the iterative setbacks encountered during the prototyping phase of engineering solutions, accounting for 10% of their grades. This grading strategy aims to normalize and encourage the fail-forward mindset, categorizing "failure" broadly to include the failure of ideas, prototypes, tests, or methods. Such an approach not only nurtures resilient and adaptive learners but also aligns with sustainable development goals, preparing students to present their innovations in a competitive Prototype Showcase, akin to real-world engineering projects and entrepreneurial ventures.

This paper also integrates a Diversity, Equity, and Inclusion (DEI) analysis to assess how the 'fail-forward learn-fast' approach influences learning outcomes across diverse demographics.

2. Background:

The exploration of failure in educational and professional contexts reveals a multifaceted phenomenon with implications for learning and innovation. Historically, failure has been examined across various disciplines from Medicine to Science, Technology, Engineering, and Mathematics (STEM), highlighting its complexity and the diverse factors that contribute to it [4-7].

In the context of engineering design, the importance of embracing failure as a critical component of the design process is increasingly recognized. Studies emphasize the need for comprehensive systems focus that encompasses all phases of a product's life [8,9]. This perspective is echoed in discussions on the educational value of failure analysis and the concept of productive failure [10,11]. Such insights suggest that understanding and analyzing failures can significantly enhance students' grasp of design processes and create an innovative mindset.

Furthermore, the fear of failure presents a notable barrier to learning and innovation, especially among engineering students. Research highlights the influence of fear of failure on students, particularly women, pointing to factors like self-efficacy, gender role conflict, and the learning environment's perceived nature [12,13]. The intergenerational transmission of fear of failure [14] and the dual role of this fear as both a hindrance and a motivator [15, 16] emphasizes the complexity of navigating failure in educational settings. The influence of educators' attitudes towards failure [17] further illustrates the need for pedagogical strategies that reshape students' perceptions of failure, promoting resilience and a success-oriented mindset.

Risk-taking, as an integral aspect of engineering education, demands a comprehensive approach to encourage students to embrace uncertainty and view failure as a learning opportunity. Research also highlights the critical role of instructors in modeling risk-taking behavior, fostering an entrepreneurial mindset essential for innovation [18, 19]. Studies on risk assessment and management [20, 21] and the impact of instructional frameworks on developing an entrepreneurial mindset [22, 23] emphasize the importance of active learning and project-based approaches in cultivating the skills needed for navigating the complexities of the engineering profession.

Existing literature emphasizes the complexity of failure and its critical role in learning and innovation. However, there remains a gap in empirical studies exploring the integration of failure journaling in engineering education to enhance the learning from failure methods. Our study addresses this gap by examining the effects of incentivizing failure documentation and reflection, contributing new insights into how a fail-forward mindset can be effectively encouraged within multidisciplinary student teams.

3. Research Methods:

This study adopts a mixed-methods approach to comprehensively investigate the impact of fostering a 'fail-forward learn-fast' mindset within an engineering education framework, specifically within the "Innovation Through Making" course. The study's design aims to assess

how reflective failure journaling, alongside diverse, equitable, and inclusive team-building efforts, influences students' attitudes towards failure, resilience, risk-taking capabilities, and learning outcomes. To explore the pedagogical impact of integrating failure journaling within engineering education, this study poses the following research questions:

1. How does incentivizing failure documentation and reflection influence engineering students' perceptions of failure?
2. In what ways does reflective failure journaling contribute to the development of a fail-forward mindset among engineering students?

3.1. Participants

The study encompasses a combined cohort of 54 students from the "Innovation Through Making" course over two academic terms, D Term 2022 (D22) and D Term 2023 (D23). Reflecting the course's cross-disciplinary appeal, participants included students majoring in Mechanical and Materials Engineering (ME), Robotics Engineering (RBE), Interactive Media and Game Development (IMGD), Computer Science (CS), Biotechnology (BIO), Civil Engineering (CE), Architectural Engineering (AE), Physics (PHY), with a demographic breakdown of 33 males, 21 females, and 1 non-binary student. The participants were predominantly second-year students, although the course attracted students from all academic years, demonstrating its broad appeal. Offered as a 3-credit engineering elective, the course provided a valuable opportunity for students across disciplines to engage with critical concepts of engineering design and innovation.

3.2. Data Collection

Data collection was conducted through several methods:

1. **Failure Journals:** Students documented their experiences with failure, reflections, and learning outcomes in a digital "Failure Journal" throughout the 8-week course. This included keeping a Summary Table to organize the ideas and prototypes explored, categorized by the testing and iteration phases. For each entry, students briefly detail the Type of Failure, Documentation (sketches, pictures, etc.), Analysis (reasons), Timeline, and Reflections- focusing on "Aha!" moments, lessons learned, and how these insights will influence future endeavors.
2. **Surveys:** Pre-course and post-course surveys based on the Student Assessment of their Learning Gains (SALG) [24] were administered to capture baseline and summative results, focusing on students' understanding of and shifts in attitudes towards failure.
3. **Interviews:** All students from the D23 cohort were invited to participate in small group interviews after the last day of classes. Ten students participated in post-course semi-structured interviews to gain deeper qualitative insights. These interviews, while guided

by a core set of questions, were not rigid. Questions were not asked verbatim, allowing flexibility to dive deeper into each student's or team's specific projects and ideas. Sample questions included:

- Can you describe a specific instance where you faced failure during the course?
- How did maintaining a Failure Journal affect your view on making mistakes?
- Reflecting on your course experience, how has your mindset towards tackling problems evolved?

The semi-structured nature of these interviews meant that the conversation could adapt based on the respondents' answers, focusing more on building upon specific teams' or students' projects and ideas. These interviews were transcribed, cleaned, and analyzed for thematic content.

4. **DEI-focused Survey Questions:** Integrated into the post course survey were questions aimed at quantitatively assessing students' perceptions of inclusivity and diversity within the course, covering aspects such as the classroom environment, curriculum development, student recruitment, diverse student teams, faculty and staff diversity, and assessment and evaluation methods.

3.3. Data Analysis

The study employed both qualitative and quantitative analysis methods:

1. **Quantitative Evaluation:** Survey responses were analyzed to identify shifts in attitudes towards failure, perceived learning gains using the SALG instrument, and the effect of DEI efforts on the learning environment. Self-assessment questionnaires were utilized to capture students' perspectives on their learning and encourage reflective thinking, essential for engineering and entrepreneurship education [25]. These assessments gauged perceived attitudinal shifts and promoted metacognitive skills critical in navigating failure and innovation.
2. **Thematic Analysis:** Interview transcripts and Failure Journals were analyzed using thematic analysis to identify common themes related to students' experiences with failure and the learning derived from these experiences.
    A. This study employs Braun & Clarke's [26] thematic analysis method due to its flexibility and robustness in analyzing qualitative data. Its validity is established through its rigorous yet adaptable framework, which accommodates a range of theoretical approaches and data types. By providing a detailed, step-by-step process for identifying, analyzing, and reporting themes, it enables a rich and detailed, yet complex account of data. This approach is conducive to uncovering the nuanced ways in which failure journaling influences engineering students’ perceptions and the development of a fail-forward mindset.

B. An inductive approach was chosen for this study to allow themes to emerge from the data without preconceived categories, thus providing a grounded understanding of the participants' experiences and perceptions. This approach is justified by its alignment with the exploratory nature of the study, aiming to uncover how failure journaling influences student attitudes and mindsets.
C. To ensure a thorough and systematic analysis of the qualitative data, the following steps were followed:

    i. Failure Journals were analyzed first to identify initial themes related to students' experiences with failure.
    ii. Subsequent interviews were conducted to dig deeper into these experiences and gather more nuanced insights. Interviews were transcribed verbatim and then analyzed, allowing for comparison and contrast with the themes identified in the Failure Journals.
    iii. An initial codebook was developed based on the analysis of Failure Journals, which was then refined and expanded through the analysis of interview transcripts.
    iv. The entire dataset was re-examined to ensure consistency in coding and to identify any emerging themes not captured initially.

3.4. Fostering Diversity, Equity, and Inclusion (DEI)

An integral component of the study was the examination of DEI efforts within the course to ensure a diverse and inclusive educational environment. Efforts to create an inclusive classroom environment were complemented by curriculum development initiatives designed to reflect a wide range of perspectives, ensuring that content was relevant and accessible to all students. Active recruitment strategies targeted students from underrepresented groups in engineering, fostering a richer, more diverse learning community. Furthermore, the deliberate formation of diverse student teams was pivotal in promoting multidisciplinary collaboration and knowledge exchange, enhancing the learning experience. The involvement of a diverse array of SME guest speakers and support staff introduced students to a broad spectrum of insights and professional experiences, further enriching the educational journey. Assessment and evaluation methods were carefully crafted to be inclusive and equitable, incorporating a variety of assessment types to fairly evaluate the diverse competencies within the student body.

3.5.Ethical Considerations

All data collection and analysis procedures adhered to ethical guidelines, ensuring confidentiality and voluntary participation. The study received appropriate institutional review board approval.

4. Results and Discussion:

4.1. Attitudinal Shifts towards Failure and Learning

Our quantitative analysis revealed significant shifts in students' attitudes towards failure, moving from avoidance to embrace (D22 Pretest: 3.4 to Posttest: 4.5; D23 Pretest: 3.5 to Posttest: 4.6). This suggests that the inclusion of failure journaling within the curriculum has a positive effect on students' perceptions of failure, promoting a more resilient and innovative mindset.

Table I presents the attitudinal shifts observed across two academic terms, D Term 2022 (D22) and D Term 2023 (D23), highlighting a consistent trend towards more positive perceptions of failure. The cohorts from D Term 2022 (D22) and D Term 2023 (D23) were distinct, with students only participating in one term.

Table I. Student Attitudes Towards 'Innovation Through Making'

	D22 Pretest	D22 Posttest	D23 Pretest	D23 Posttest
Presently, I am.....				
Open to embracing and learning from failure	3.4 (1.0)	4.5* (0.8)	3.5 (1.1)	4.6* (0.7)
Willing to engage in risk-taking design and prototyping projects	3.3 (0.9)	4.6* (0.7)	3.4 (1.0)	4.7* (0.6)
Comfortable with iterative design and prototyping	3.1 (1.2)	4.8** (0.8)	3.2 (1.3)	4.9** (0.7)
Resilient in facing engineering challenges	3.0 (1.1)	4.7** (0.9)	3.1 (1.2)	4.8** (0.8)

*p < .05, **p < .01. Standard Deviations appear in parentheses below means. Likert Scale 1-6.

These shifts are critical in the context of engineering education, where the ability to navigate setbacks is paramount. The increase in students' openness to embracing failure aligns with literature emphasizing resilience as a key component of engineering innovation [1, 5, 6, 8].

The total failure count (number of failures that students noted in their journals), and diverse range of final prototyping projects proposed by student teams exemplifies the application of a fail-forward mindset in addressing real-world problems, as shown in Table II.

Table II. Sample Prototyping Projects Proposed by Student Teams and Failure Count

Project	Description	Failure Count	Unique Majors
VR Force Feedback Glove	A feedback control device for VR with applications in medical and emergency training services	22	4
StovaDonna	Device to prevent accidental household fires	15	4
Noverdose	Device to prevent opioid abuse	15	4

WARK	Device to clear trash from water bodies	10	4
Eco Sensor	Device to track and aggregate indoor air quality data across colleges	8	5
SAFE	Novel mechatronic solution to address food insecurity	7	4
SimpliRack	Innovative low-cost solution for an educational tool rack	8	3
Helping Hands	Elder Care and Assistive Device	16	5
VR Ski Trainer	A Training VR Goggle for skiing and snowboarding	20	6

These projects highlight the interdisciplinary collaboration and creativity encouraged by the course, emphasizing the practical application of a fail-forward approach. They also serve as a qualitative reflection of students' ability to solve real problems through the application of skills learned throughout the course.

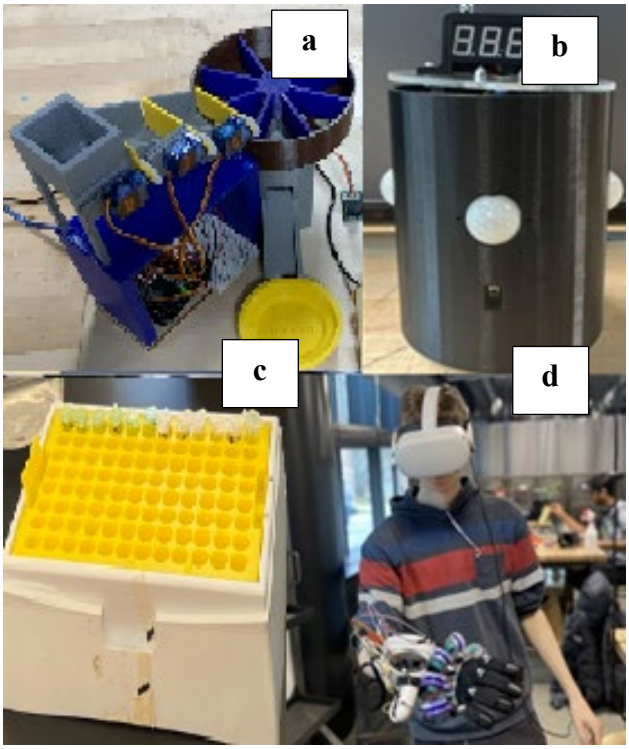

Figure 1. Successful student prototypes from the course showing a) Helping Hands, b) StovaDonna, c) SimpliRack, and d) V.R Force Feedback Glove

4.2. Preliminary Qualitative Insights

Preliminary qualitative findings, derived from a thematic analysis of failure journals and interviews, offer insights into the nuanced experiences of students engaging with failure journaling.

We identified four key themes that reflect the impact of the 'fail-forward learn-fast' mindset within the course, as shown in Table IV.

Table IV: Thematic Analysis Table

Theme	Concept	Sub Theme	Data Sources
Normalization of Failure	Fail and learn	Learning from Failure	Failure Journals & Interviews
	Setbacks are okay	Acceptance of Setbacks	Interviews
	Incentives to take risks and fail	Encouragement for Risk-Taking	Failure Journals
	Perfectionism is overrated	Moving Beyond Perfectionism	Interviews
	Embracing Mistakes	Viewing Mistakes as Opportunities	Failure Journals & Interviews
Enhanced Risk-Taking	Dare to Try	Willingness to Experiment	Interviews
	Learning new things	Discovery and Learning	Failure Journals & Interviews
	Risky Innovations	Innovation through Risk	Failure Journals
	Uncertainty is cool	Embracing Uncertainty	Interviews
	Venturing Beyond Comfort Zones	Exploring New Boundaries	Failure Journals & Interviews
Growth Mindset Development	Grow from Errors	Learning and Growth from Mistakes	Failure Journals & Interviews
	No silly ideas	Valuing All Ideas	Interviews
	Continuous Improvement	Pursuit of Excellence	Failure Journals
	Challenge Accepted	Embracing Challenges	Interviews
	Different skills working together	Integrating Diverse Skills	Failure Journals & Interviews

Diversity in Problem-Solving	Teamwork Diversity/ Varied Perspectives	Multidisciplinary Collaboration	Failure Journals
	Unique Insights	Value all perspectives	Interviews
	Collaborative Creativity	Foster Creativity	Failure Journals & Interviews

4.2.1. Normalization of Failure

The keywords related to "**Normalization of Failure"** reflected a positive shift in students' perspectives on failure. Most students described failure not as an endpoint but as an essential step in the learning process. For instance, a student working on the "VR Force Feedback Glove" project remarked, "*We changed our design more than 5 times due to various issues. Facing multiple failures in our design made us rethink and ultimately improve our prototype. Each setback was a step forward*." Several students also remarked that the incentivizing of failure (through 10% of points allotted to the failure journal) helped with normalizing failure, marking a departure from the traditional educational practices that may treat failure negatively.

"*At first, keeping track of what went wrong in my Failure Journal felt wrong, but those began to feel like right steps the more I worked on them. It's kind of wild how what used to stop me in my tracks now feels normal*". This change in perspective is not only reflective of the course's innovative pedagogy but also resonates with existing literature that highlights the integral role of failure in driving innovation and growth [5, 8].

4.2.2. Enhanced Risk-Taking

The analysis indicated a heightened willingness among students to venture beyond their technological comfort zones. A participant from the "Noverdose" team highlighted, "*Working on Noverdose pushed us to explore concepts and designs that none of us knew anything about. It was about risking failure for a potentially great solution with a lot of value*." They later comment: *"It's like the journal gave me confidence to throw wild ideas into my projects, knowing it's all part of the game."*

This approach mirrors findings from the literature that stress the importance of risk-taking in engineering education [15, 16], suggesting that confronting and learning from failure can significantly bolster students' innovative capacities.

4.2.3. Growth Mindset Development

Emerging strongly from the data were the codes "Growth Mindset" and "Learning from Mistakes", illustrating the development of a growth mindset among participants. Students expressed an increased recognition of learning opportunities from mistakes, indicative of a deeper cognitive transformation. For example, a student involved in the "Helping Hands "project

says: *'Now I am like…tell me more so I can grow.' I now feel like errors aren't setbacks; they're improvements. That's a game-changer*."

This reflects the broader educational narrative that promotes the growth mindset as critical for resilience and continuous improvement in engineering practice [5, 6].

4.2.4. Diversity in Problem-Solving

Intentionally creating teams of students from diverse academic backgrounds highlighted the value of multidisciplinary collaboration in fostering diverse problem-solving approaches. A reflection from the "SAFE" project team encapsulated this: "Collaborating with students from different majors brought unique insights that improved our project, we learned a lot of cool stuff from each other.". A student from the 'Noverdose' project said: "*Working on 'Noverdose', I saw firsthand how diverse perspectives lead to breakthroughs. It's not just about combining skills… it's about how those different viewpoints might spark creativity.*". This finding aligns with the DEI objectives of the course and reinforces the literature on the benefits of diversity in enhancing creativity and problem-solving in engineering education [15, 16].

These themes collectively emphasize the effectiveness of the 'fail-forward learn-fast' mindset in cultivating an environment that encourages risk-taking, embraces failure, and leverages diversity for innovation. The course's approach, as reflected in the thematic analysis, not only facilitates technical skill development but also raises critical soft skills such as resilience, adaptability, and collaborative problem-solving.

The DEI-focused survey questions revealed students' perceptions of the course's inclusivity and diversity efforts:

- Inclusive Classroom Environment: High levels of inclusivity were reported, with an average rating of 4.2 out of 5, indicating the successful creation of a welcoming atmosphere conducive to learning from failures.
- Curriculum Development: The representation of diverse perspectives in the curriculum received a moderate score of 3.1, suggesting areas for improvement to better reflect the diversity of student experiences.
- Diverse Student Teams: Students valued the effectiveness of diverse teams, with an average rating of 4.3, highlighting the benefits of varied academic and cultural backgrounds in enhancing learning and innovation.
- Faculty and Staff Diversity: The diversity among SME guest speakers and support staff received positive feedback, averaging a score of 3.9, enhancing student engagement and providing a richer learning experience.

Our DEI analysis suggests that inclusive classroom environments and diverse team dynamics contribute positively to students' willingness to engage with failure constructively. These findings suggest that diversity and inclusivity are not just ethical imperatives but foundational to cultivating an environment where students feel safe to take risks, fail, and learn, thereby enhancing their resilience and innovative capabilities. However, these preliminary findings call

for further validation through comprehensive analysis and the application of suitable assessment instruments.

4.3. Study Limitations:

While this study provides valuable insights into the benefits of fostering a fail-forward mindset in engineering education, it is not without its limitations. One of the primary constraints is the relatively small sample size and the specific context of a single course at one university, which may limit the generalizability of the findings to other institutions or disciplines. To address the limitations identified, future research should aim to replicate this study across multiple courses and institutions. Such studies could provide a broader validation of the fail-forward pedagogical approach and its applicability in diverse educational settings.
Additionally, the reliance on self-reported measures in surveys and journals, while insightful, may introduce bias as students could overestimate their growth or underreport their challenges due to social desirability or personal reflection limitations. Furthermore, the study's duration may not fully capture the long-term impacts of the fail-forward approach on students' professional growth and mindset. These limitations suggest a need for further research involving larger, more diverse cohorts, longitudinal studies to track long-term outcomes, and the incorporation of more objective measures of learning gains and innovation capabilities.

5. Conclusion

This study provides a compelling look into the transformative potential of integrating a fail-forward mindset within the "Innovation Through Making" course at Worcester Polytechnic Institute. Our findings show a significant shift in engineering education- moving from a traditional emphasis on avoiding failure to a progressive embrace of failure as an essential learning tool. The positive changes in student attitudes, alongside the development of diverse, innovative projects, show the effectiveness of reflective failure journaling in encouraging resilience, creativity, and a growth mindset.

The key themes identified—Normalization of Failure, Enhanced Risk-Taking, Growth Mindset Development, and Diversity in Problem-Solving—serve as evidence for educators aiming to cultivate similar environments in their engineering courses. To this end, we propose several strategies:

- **Incorporate Reflective Journaling**: Educators should integrate structured, reflective journaling activities that encourage students to document and critically reflect on failures and setbacks encountered during the course. This practice should be framed positively, emphasizing the learning opportunities that arise from each failure.
- **Facilitate Open Discussions About Failure**: Creating a classroom culture that openly discusses failures can demystify and destigmatize the concept of failing. Educators can

lead by sharing their own experiences with failure or by inviting professionals who can speak on the subject.
- **Diverse Team Collaboration**: Encourage project-based learning that involves forming teams with diverse backgrounds and skill sets. This approach not only mirrors real-world engineering challenges but also enhances problem-solving capabilities and creativity.
- **Implement DEI Initiatives**: Our findings highlight the importance of DEI in creating a supportive learning environment. Educators should strive to develop curricula that reflect diverse perspectives and actively recruit a varied student body to enrich the educational experience.

Looking ahead, there is a clear avenue for future research to explore the longitudinal influence of failure journaling on students' career development and industry readiness. Such studies could further validate the role of a fail-forward mindset in preparing engineering graduates to navigate the complexities and uncertainties of the professional world.

In conclusion, the "Innovation Through Making" course represents a forward-thinking model for engineering education, aligning with the evolving needs of industry and society at large. By embracing failure, encouraging risk-taking, and fostering diversity, the course prepares students not just as engineers, but as innovators and problem-solvers ready to make meaningful contributions to their fields. Our study lays the foundation for a broader application of these pedagogical approaches, establishing the stage for a new generation of resilient, adaptable, and innovative engineers.

References

[1] A. Winkens and C. Leicht-Scholten, "Does engineering education research address resilience and if so, how? – a systematic literature review," *European Journal of Engineering Education*, vol. 48, pp. 221-239, 2023.

[2] Kern Entrepreneurial Engineering Network, "Engineering unleashed," 2024. [Online]. Available: https://engineeringunleashed.com/.

[3] A. Dorland, "Failing to Learn: Design Thinking and the Development of a Failure-Positive Mindset in the University Classroom," *Collected Essays on Learning and Teaching*, 2023.

[4] G. Lampropoulos, "Failure in psychotherapy: an introduction," *Journal of clinical psychology*, vol. 67, no. 11, pp. 1093-1095, 2011.

[5] R.L. Wears and A.W. Wu, "Dealing with failure: the aftermath of errors and adverse events," *Annals of emergency medicine*, vol. 39, no. 3, pp. 344-346, 2002.

[6] T. Akagaki and K. Katô, "Ferrographic analysis of failure process in a full-scale journal bearing," *Wear*, vol. 152, pp. 241-252, 1992.

[7] V. Prabhakaran, A.C. Arpaci-Dusseau, and R.H. Arpaci-Dusseau, "Model-based failure analysis of journaling file systems," in *2005 International Conference on Dependable Systems and Networks (DSN'05)*, pp. 802-811.

[8] N. J. Delatte, "Using failure case studies in civil engineering education," in *Forensic Engineering*, 2000, pp. 430-440.

[9] R.S. Ryan, "The role of failure/problems in engineering: A commentary of failures experienced - lessons learned," 1992.

[10] H. Medoff, "Incorporating failure analysis into engineering design," in *Proceedings of IEEE Frontiers in Education Conference - FIE '93*, pp. 214-215.

[11] M.L. Johnson, G.J. Kelly, and C.M. Cunningham, "Failure and Improvement in Elementary Engineering," *Journal of Research in STEM Education*, 2021.

[12] K.L. Nelson, D.N. Newman, R.G. McDaniel, and W.C. Buboltz, "Gender Differences in Fear of Failure amongst Engineering Students," in *International Journal of Humanities and Social Science*, 2013.

[13] K.L. Nelson, "Examining the effects of fear of failure, self-efficacy and gender role conflict in male and female engineering students," 2012.

[14] A.J. Elliot and T.M. Thrash, "The Intergenerational Transmission of Fear of Failure," in *Personality and Social Psychology Bulletin*, vol. 30, pp. 957-971, 2004.

[15] A.J. Martin and H.W. Marsh, "Fear of failure: Friend or foe?" *Australian Psychologist*, vol. 38, pp. 31-38, 2003.

[16] D. Budny and J. Tartt, "Do engineering students fail because they don't know how to fail?" in *2009 39th IEEE Frontiers in Education Conference*, pp. 1-7.

[17] P.S. Lottero-Perdue and E.A. Parry, "Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering," in *Journal of Pre-College Engineering Education Research (J-PEER),* 2014.

[18] Y. Tekmen-Araci, "Teaching risk-taking to engineering design students needs risk-taking," *Art, Design & Communication in Higher Education*, 2019.

[19] E. Jablonski and N. Postdoc, "Fostering Intra- and Entrepreneurship in Engineering Students," ASEE, 2014.

[20] N. Stacey, "Briefing: Educating new engineers about risk: the risk education network," ASEE, 2014.

[21] Y. Guntzburger, T.C. Pauchant, and P.A. Tanguy, "Empowering Engineering Students in Ethical Risk Management: An Experimental Study," *Science and Engineering Ethics*, vol. 25, pp. 911-937, 2018.

[22] D. Ifenthaler, Z. Siddique, and F. Mistree, "Designing for open innovation: Change of attitudes, self-concept, and team dynamics in engineering education," in *Emerging Technologies for STEAM Education: Full STEAM Ahead*, 2015.

[23] E. Pluskwik, E. Leung, and A. Lillesve, "Growing Entrepreneurial Mindset in Interdisciplinary Student Engineers: Experiences of a Project-Based Engineering Program," ASEE, 2018.

[24] E. Seymour, D. Wiese, A.-B. Hunter, and S. Daffinrud, "Creating a Better Mousetrap: On-line Student Assessment of Their Learning Gains," 2000.

[25] S.R. Brunhaver, J.M. Bekki, A.R. Carberry, J.S. London, and A.F. McKenna, "Development of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA)," *Advances in engineering education*, vol. 7, 2018.

[26] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77-101, 2006.