

MIT Open Access Articles

Design Experiences as Pathways for Embracing Failure

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Das, Madhurima and Yang, Maria C. 2021. "Design Experiences as Pathways for Embracing Failure." Volume 4: 18th International Conference on Design Education (DEC).

As Published: 10.1115/detc2021-71419

Publisher: American Society of Mechanical Engineers

Persistent URL: <https://hdl.handle.net/1721.1/154884>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of Use: Article is made available in accordance with the publisher's policy and may be subject to US copyright law. Please refer to the publisher's site for terms of use.



DESIGN EXPERIENCES AS PATHWAYS FOR EMBRACING FAILURE

Madhurima Das and Maria C. Yang

Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

ABSTRACT

There is a growing movement in engineering and industry for students and practitioners to learn to embrace failure and develop resilience. The design process is naturally full of iteration and failures that can inherently be leveraged as learning opportunities for students. This study establishes a set of failure-related interventions implemented in an introductory design course, and then examines potential links to students' experiences and attitudes towards failure. These interventions included a failure-themed "speaker seminar" series, a virtual gallery of design mistakes ("mistake museum"), and the introduction of a prototype logger for students to intentionally reflect on each iteration of their own design projects, including what went wrong and what was learned from the iteration. Students found these interventions to be effective in gaining perspective on failure and learning to embrace it. Students' perceptions of the openness to failure of the class, perceptions of the field of design's openness to failure, and perceptions of their major's openness to failure all changed significantly, while their perceptions of their own openness to failure and their academic institution's openness to failure were unchanged over the duration of the design course. Students also self-reported that the reflective processes of logging prototypes made them feel more comfortable with failure.

1. INTRODUCTION

1.1 Motivation and Background

Undergraduate engineering students have often been taught to value success and avoid failure. Many high achieving students experience their first failures in college: realizing their hardest efforts may not be enough to get the grades they had in high school, or discovering a project isn't working as planned. Especially troubling is that girls tend to have a greater fear of failure, a gap that becomes more disparate amongst top-performing students [1]. This can be debilitating for all students, and many see it as a sign of personal weakness. Existing research shows that experiences with failure are associated with guilt and shame [2,3], quitting [4], and lower expectancies of future success [2]. However, becoming comfortable with failure is a crucial skill for personal growth.

Traditional approaches towards failure typically target student self-confidence or beliefs about their intelligence, but several studies recommend instead allowing students to experience failure firsthand in their learning environments [5]. Learning from failure is essential in tackling new problems, especially the kind that engineering students hope to solve at the cutting edge of industry and academic research.

A key component of undergraduate engineering curriculum, as defined by the criteria for ABET, is to allow students experience with the design process [6]. Sketching, physical prototyping, and iterating on ideas are essential parts of the design process [7,8]. Prior work shows that rapid iteration through prototyping during the early stages of a design process correlates with better design outcomes [9]. However, in order to iterate on concepts, designers must first accept that there is room for improvement in their ideas.

As such, the iterative design process is an appealing context for promoting learning through failure [5]. The design firm IDEO famously says "fail often to succeed sooner," showing that practitioners also find value in failure in the context of prototyping [10]. The process of addressing a new problem or designing a new concept centers around failure: learning from the failure and iterating to achieve a better solution. For students used to perfection, dealing with failure is one of the most difficult parts of learning to design as they often struggle to let go of an idea they have fallen in love with, even if it doesn't work. The goal of this work is to use experiences with design to flip the negative mindset about failure and help students in embracing and learning from it to prepare students for future engineering careers. This work involved assessment of perceptions of failure, engineering identity, growth mindset and grit in a project-based design course that included activities focused on normalizing failure.

Research Questions:

RQ 1: *Do intentional experiences with low-stakes failure through the design process change undergraduate student attitudes towards failure?*

RQ 2: Do opportunities for reflection during the design process impact student perceptions of failure and propensity towards embracing failure?

1.2 Prior Art

There is prior research that considers how students respond to failure both in open-ended projects and in other contexts. Literature shows that engineering students often tend to move from a growth mindset (believing that intelligence can be developed) to fixed mindset (believing that intelligence is innate) during their first year in college, but that experiences with open-ended design projects mitigate some of this shift [11–13]. Fear of failure is also correlated with low engineering design self-efficacy [14]. Students even at the elementary and middle school level struggle with receiving feedback when they perceive it as a sign of failure [15]. Experiences with design at that young age have been successfully used to transform student attitudes towards embracing failure [5,15]. Additionally, there is evidence that structured reflection during the design process helps designers make better decisions [16]. However, the value of reflection with regard to student attitudes towards failure has been less formally studied.

Despite the promising prior art showing that design experiences can shift student attitudes, there has not been considerable work in the area of using design experiences to help undergraduate students embrace failure in particular. This study aims to bridge this gap in the research by proposing and evaluating a series of interventions aimed at explicitly encouraging undergraduate engineering students to embrace failure. These include listening to speakers from the university community, reflecting on their own personal experiences during the design process and with failure, and experiencing repeated low-stakes failures through the iterative design process.

2. METHODS

For the purpose of this study, “low stakes” failure is defined as failure that does not have a negative impact on the students’ performance in the course. To assess students’ attitudes towards failure in response to “low stakes” design failure through iteration, two main elements were introduced into a project-based design class to directly address the notion of failure: a “failure seminar” series, and a “mistake museum.” Data on student perceptions of failure was captured through surveys along with assessments of growth mindset, grit, and self-efficacy at the beginning, mid-point, and end of the course. Figure 1 shows the timeline of surveys and interventions in the course.

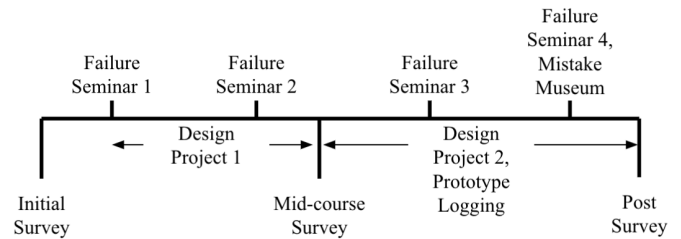


Figure 1: Timeline of the course and the failure-related interventions

2.1 Class Context

The course studied was an introductory level half semester design class for Mechanical Engineering undergraduates at a northeastern US university. The course is a team-based, project-oriented, hands-on design-and-build course that was taught in an entirely remote setting. Students were provided with substantial kits of materials and tools for prototyping remotely. Students completed two design projects throughout the eight weeks of the course. Seven men and twelve women, all first years or sophomores, were enrolled in the course from start to finish. Eleven students were in Mechanical Engineering, three students were in Computer Science and Engineering, one student was in Architecture, one student was in Biological Engineering, and three were undecided regarding their major.

2.2 Failure Seminars

The topic of failure was first addressed through a “Failure Mini-Seminar Series.” Four guest speakers from the university community were invited to share a short story of personal or professional failure with the class. These speakers were individuals who were considered examples of “success,” but were willing to share stories of failures with the class and spoke for about 10-20 minutes at the beginning of class. The goal of this repeated exposure to hearing stories of others’ failures is to build a community that is eager to learn from failure and be open about experiences with failure. The four speaker backgrounds and topics are described in Table 1 below.

After each failure seminar, students were asked to write a brief reflection on that day’s seminar as part of their homework. These reflections took different forms, such as connecting the speaker’s story to a personal example or writing down key takeaways from the story.

Table 1: Description of each seminar speaker’s background and the topic they spoke about

Failure Seminar speaker	Topic
1: Professor of the course (and co-author)	Story of academic failure and embarrassment from her experience as an undergraduate. This was meant to set the stage and shared understanding of attitudes for the course and course staff.
2: Undergraduate admissions officer, former graduate student at the institution	Experience struggling simultaneously with graduate work, the death of a friend, and trying to run marathons as a coping mechanism.
3: Senior lecturer in department	Two “speaker bios” of herself: one was the story of successes that is typically used when she is introduced at conferences and as a guest speaker, whereas the other was the story of the underlying failures and qualifying statements that often plays in her head. This prompted a subsequent discussion around imposter syndrome.
4: Well-recognized professor in the department, expert on learning	An experience with failing a class as an undergraduate and how it rewired how he approached his academics.

2.3 Prototype Logger and Mistake Museum

During the second design project in the class, students were asked to reflect on each prototype that they created by completing an online prototype logging form. They received weekly reminders to continue filling these logs out. The form asked students to list the date the prototype was made, a short text description of the prototype, 1- 5 images of the prototype, and a brief description of what they learned from the prototype. This was meant to help them reflect on the purpose of each iteration and codify the process of learning from failure and iteration during the design process. A secondary goal of the prototype logger was to help students build a habit of recording their design process as preparation for creating portfolios.

Near the end of the second design project, students were also asked to create an entry for the “Mistake Museum,” a display of artifacts of failure from their projects along with reflections on what was learned from the mistake. Displaying these items as milestones in the learning process was intended to help students celebrate mistakes and to visually display failure as a key part of design.

2.4 Surveys of Attitudes Towards Design and Failure

The primary methods of data collection were surveys and class assignments. Students were given a fifteen-minute pre-survey before the first class to collect demographic information and assess baseline attitudes, skill levels, and prior experience in design. They were also asked a series of questions about what they perceive as academic and social failures. Examples included failing an exam, creating a final project that turns out worse than intended, not being involved enough socially, and overcommitting to extracurriculars. Subsequently, they were asked to rank their responses in order of magnitude. Additionally, they were asked what kinds of measures might make them more comfortable with failing and were asked to rank their responses in order of effectiveness. These included having professors share stories of failure, removing emphasis on exams, and the ability to drop a homework assignment without penalty.

The end of course survey included specific questions about the interventions in the class such as the failure seminars and prototype logger and how they influenced students’ perceptions of failure. For each intervention, they rated the impact on their attitude/perception of failure as “Made me much less comfortable with failure,” “Made me a little less comfortable with failure,” “My perception of failure was unchanged,” “Made me a little more comfortable with failure,” or “Made me much more comfortable with failure.”

All three surveys (pre-, mid-, and post-class) also included the grit instrument, a modified mindset (fixed vs. growth mindset) instrument, and a self-efficacy and failure index [1,17,18]. Additionally, students were asked each time to describe their definition of failure and answer several questions about the “openness” of different entities to failure. They were asked the following:

- How open to failure they are as an individual
- How open their major is to failure
- How open the university is to failure
- How open the field of design is to failure

Students were also asked how open this specific design class is to failure after the first and second project (not asked in the pre-course survey). Each of those “openness” questions was answered with a rating on a scale of 0-10. Students also explained each rating with a written response.

An intergovernmental organization aimed at encouraging economic progress, The Organisation for Economic Co-operation and Development (OECD), established indexes of self-efficacy and of failure based on student responses to a series of eight questions [1]. The students in the course studied here were given these same questions in all three surveys. These asked students to respond to each question with “Strongly Disagree,” “Disagree,” “Agree,” or “Strongly Agree.”

The five self-efficacy questions were:

- I usually manage one way or another
- I feel proud that I have accomplished things
- I feel that I can handle many things at a time
- My belief in myself gets me through hard times
- When I'm in a difficult situation, I can usually find my way out of it

The three failure-related questions were:

- When I am failing, I worry about what others think of me
- When I am failing, I am afraid that I might not have enough talent
- When I am failing, this makes me doubt my plans for the future

3. RESULTS AND DISCUSSION

3.1 In-Class Interventions

Failure Seminars

The majority of students reported that listening to the failure seminars made them more comfortable with failure. Around 79% of students reported that the first failure seminar, done by the professor of the course, made them more comfortable with failure. Around 63% of students reported that the second failure seminar, done by an admissions officer from the university, made them more comfortable with failure. Around 79% of students reported that the third failure seminar, done by a senior lecturer in the department, made them more comfortable with failure. Around 84% of students reported that the fourth failure seminar, done by a well-recognized faculty member in the department, made them more comfortable with failure. Notably, around 63% of students reported that this fourth and final failure seminar made them much more comfortable with failure.

Students were also asked about their experience with writing reflections after the failure seminars. Around 53% of students reported that writing reflections on the failure seminars made them more comfortable with failure.

The first failure seminar was done by the course professor, who shared an example of being berated by a professor when she was an undergraduate student. Students were asked to reflect on this story and write down a failure-related experience from their own lives. They tended to share personal stories that were similar to the one the professor shared, failures that made them scared to ask questions or made them uncertain about their relationship with teachers and professors after being embarrassed.

The second seminar, by an admissions officer and former graduate student at the university, shared an example of failure that involved losing a friend in a tragic accident and using that as motivation to achieve certain athletic goals. He also talked about the admissions process and specifically mentioned that the university looks for indicators of how prospective students handle failure in their applications, and whether or not they are

willing to ask for help. Students reflected on specific aspects of the story, with comments like:

"I was really inspired about the fact that [he] came from a family of rather non-athletic people but this didn't cause him to set a lower bar for himself – he literally set the bar as high as it can go for running, and then set upon doing it."

One student resonated with the experience of losing a friend: *"...I was reminded of the loss of my friend from this semester. I was surprised at how resilient [he] must be to be able to participate in an event that probably reminds him of his loss and grief over the death of his friend..."*

Others reflected on the larger meaning of his comments related to them directly:

"unrelated to his personal story, but the reminder that each one of us have the capability to do well and succeed at [the university] and beyond was comforting – this semester has been rough for myself and many of my peers, and I find that such reminders often put things in perspective."

Another student was surprised by his comments about what the admissions office looks for in prospective students:

"...it was really interesting to hear him talking about how something they look for is that students are able to find help when they are struggling with something instead of trying to do everything on their own... in the future I will be more aware of when I need to ask for help instead of trying to push that feeling aside...he was able to remove a lot of the negative connotations that come with asking for help and pointing out how failure is normal and therefore asking for help is also normal since that is a necessary part of overcoming failure."

The third seminar was by a senior lecturer in the department who had done her undergraduate and graduate work at the university as well. She shared a "success" and a "failure" introduction in order to shed light on how people portray themselves externally compared to what their internal monologues sometimes sound like. Students loved her seminar, saying:

"[her] talk has been my favorite so far, because she actually gave a tangible example of a "failure" but she's still doing fine. I feel like as a student, grades still even in university can feel like an end all be all, but her story was a good reminder of how in the long run they don't have too much of an impact."

Students also had realizations about their own imposter syndrome:

"I was very inspired by [her] story of comparing her two introductions. I have gotten awards in the past and have heard speeches of myself like the first version [she] said, but I realized that I never really think much of it because in my mind, it plays out like the second version. It also made me wish I had heard this before college applications, because

when I was trying to find stuff about me to put on them, I could only think about the second version. Maybe if I had heard the first version, I would've understood to look at the end results of what I've done, like to focus on the good parts. Even now, I'm starting to write my resume, so this talk will be so, so helpful in seeing myself in a positive light, and pulling out all the positives from things I've done."

Students found takeaways in this seminar beyond academic contexts:

"the part that struck me the most about [the] seminar was when she said that I don't have to be the best part of everyone I know. It can be easy with social media...to see people doing amazing things and showing off their talents and sometimes it is hard not to compare myself to these people... [the] seminar did a good job of showing that no one's story is comprised of only success or only failure, there is always both and it is important to keep that in mind when I feel like I am only failing and on the opposite side of the spectrum if I feel like I am only succeeding then I am probably not challenging myself enough or not being truly honest with myself and this to me is another type of failure."

The final seminar was by a senior faculty member in the department who spoke about failing a college-level course and about not meeting his parents' expectations. One student reflected:

"Today's failure discussion came at the perfect time, especially the part about fear of failure. The notion of perfection as a leash deeply resonated with me and although I can't completely rid myself of this fear of imperfection, these words were comforting to hear and definitely relieved a good amount of the stress I've been putting on myself. This seminar inspired me to slowly open myself up to failure and rather than "forgive" myself for mistakes, I will try to embrace these, reflect and learn from these experiences, rather than repressing them out of shame."

The idea of parental expectations resonated with students deeply:

"While all of the failure seminars have been insightful, I felt that I could relate to this one the most, because of the ideas of parental pressure...I always thought that it would be a major issue if I didn't do well in a class, but the failure seminar made me rethink that. When talking about his parents' reaction to him getting an F, I thought about how conversations with my parents would go if that happened to me. Honestly, I don't think they would be happy about it, but I think they would understand, and I feel a lot less pressure now that I've reconsidered their reaction if I were to do poorly in a class."

Students also felt that his take on learning to embrace failure as a process was very helpful:

"Embracing failure has been a long journey for me.' This is a quote that really resonated with me, because no matter how many times I hear to embrace failure and no matter how much

I want to and tell myself that I do, when placed in a situation of failure, I have tremendous fear. Especially in the COVID world with school, I feel myself slipping in grades, not necessarily because of the work but because I'm struggling to find motivation...I need to embrace that failures happen-they've happened for me in a few of my exams this semester. But it's how you pick yourself up from them in my experience is what truly matters."

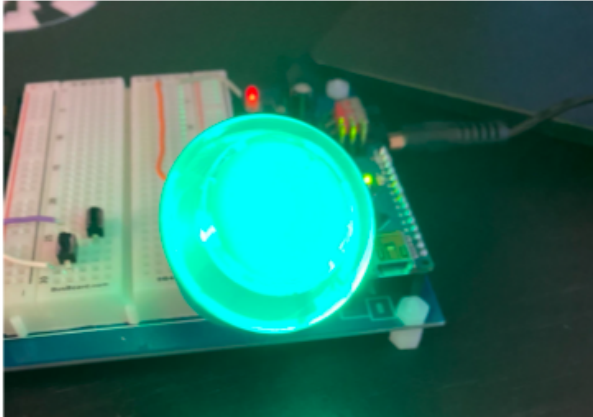
These reflections were very insightful and show that each type of seminar resonated in different ways with the students. One common theme was that students most appreciated the seminars that involved higher-stakes failure such as failing a class (as in Seminar 4). Additionally, students valued the connections that they could make to their own lives. For instance, the second speaker's comments about the admissions process were very reassuring to the students in reflecting on their own experiences with imposter syndrome. Similarly, the third speaker's structure of discussing a failure introduction inspired students to reframe the way they think about their own accomplishments and the way they perceive others' accomplishments. It was also helpful for students to hear these speakers share stories from when they were around the students' age to provide perspective that failures at that age do not determine your eventual future success.

Prototype Logger and Mistake Museum

In the post-course survey, around 58% of students reported that the Mistake Museum exercise made them more comfortable with failure. An example mistake museum entry is shown in Figure 2 below. Similarly, around 74% of students reported that the prototype logger made them more comfortable with failure, likely due to the built-in reflection component of the logger and its repeated use throughout the course.

Students' learning outcome reflections over time showed some of their personal reactions to setbacks in addition to the technical learning on how to address issues with their prototype. Figure 3 shows examples of images submitted to the prototype logger at different stages of the design process. Each photo was accompanied by comments about what the student learned from the prototype. The student initially wrote "I learned that this might not actually work, and that I am going to have to figure out a better way to create this circuit." The next day, he iterated on his circuit and logged a plan for moving forward "It worked!!! Just need to..." The following day he wrote that he learned "That this thing is actually going to work and I didn't think it would, all I need to do is..." Those who logged prototypes more often seemed to include more of these personal details and excitement rather than focusing solely on the prototype and its technical specifications.

Example Mistake Museum Entry



Remember all your measurements. In the attached image, there is an arcade-style button lit up at 5V, and a spare OLED display beneath it. My project features a clock system with adjustable alarm times and lengths for the alarm, controlling a light system that acts as the alarm. To display information, an OLED like the one depicted below is used. Buttons allow the user to make changes to the system.

Unfortunately, while I was busy verifying the circuit would work, I accidentally let the size of the buttons slip past. Thus, we have a comical size difference between the button and OLED.

Figure 2: One student's Mistake Museum submission showing the image and text submitted for his entry.



Figure 3: Two images submitted by a student to the prototype logger of a two iterations of a design

3.2 Changes in Scores

Attitudes towards Failure

Several measures of student attitudes towards failure were measured before the class, after the first project, and at the end of the class. Two students' responses were disregarded- one had not completed the survey at the beginning of the class, and one did several of his post-scores using a new and very different definition of failure from his initial scores. His score was disregarded in the categories where he included a comment explaining that his numerical score did not match his

understanding of how open each category was to failure.

The Friedman statistical test was used to assess whether or not scores changed significantly for the measures that were assessed before, during, and after the course because the scores were from a single set of students measured three times and the data is not parametric. The Dunn-Šidák post-hoc test was used to subsequently determine which of the 3 groups were significantly different. The measures that were only assessed twice during the course were compared using the Wilcoxon Signed Rank test because they were paired scores and non-parametric.

Student responses to the question "On a scale of 0-10, how open do you think the field of design is to failure?" changed significantly from the beginning to the end of the course. A Friedman test indicated that perception of the field of design's openness to failure was greater at the end of the course (Median=9.00, Mean= 8.16) than at the beginning of the course (Median= 7.00, Mean= 6.79) with a p-value of 0.0292.

Similarly, a Friedman test indicated that perception of their major's openness to failure on a scale of 0-10 was greater at the end of the course (Median= 5.50, Mean= 6.17) than at the beginning of the course (Median=5.00, Mean= 4.61) with a p-value of 0.0007. This perception shift happened both for students within the Mechanical Engineering department and students who planned not to major in Mechanical Engineering.

For students within the Mechanical Engineering department, there was a statistically significant difference between their perceptions of the major's openness to failure between the beginning and end of the course as well as the middle and end of the course. Mechanical Engineering students' perception of the major's openness to failure was greater at the end of the course (Median= 5.50, Mean= 6.50) than at the beginning of the course (Median=5.00, Mean= 4.70) and was also greater at the end of the course (Median= 5.50, Mean= 6.50) than at the middle of the course (Median=5.00, Mean= 5.40) with a p-value of 0.0058.

For students outside of the Mechanical Engineering department, there was a statistically significant difference in their perceptions of their major's openness to failure between the beginning and end of the course as well as the beginning and middle of the course. Due to the small sample size of non-Mechanical Engineering students ($n= 7$), post-hoc testing could not be used with the Friedman test. Non-Mechanical engineering students' perception of the major's openness to failure was greater at the end of the course (Median= 6.00, Mean= 6.43) than at the beginning of the course (Median=5.00, Mean= 4.43) and was also greater at the middle of the course (Median= 6.00, Mean= 5.71) than at the beginning of the course (Median=5.00, Mean= 4.43) with a p-value of 0.0281.

The question of “Please indicate how open to failure you believe this class is” was asked twice- once after the first design project and once at the end of the class/after the second design project. A Wilcoxon Signed Rank test indicated that perception of this design class’ openness to failure was greater at the end of the course (Median= 9.00, Mean= 8.94) than at the beginning of the course (Median=8.00, Mean= 7.67) with a p-value of 0.0088.

Several categories of attitudes also did not see statistically significant changes. This included perceptions of oneself’s openness to failure and the university’s openness to failure. At no point were there significant differences in any category by gender. Additionally, student grit and mindset scores didn’t change significantly. However, the number of students exhibiting a mindset score in the “growth mindset” category started at 10 at the beginning of the course, decreased to 8 after the first project, then went up to 13 by the end of the course. This finding is consistent with other studies that have found students participating in open-ended design-based experiences to initially have a decreased growth mindset and then subsequently see an increase in their mindset scores [11,13].

The interventions and class experience appeared to change students’ perceptions of design, the class, and the major with respect to failure, but did not change their perceptions of themselves or the university. It is reasonable to understand how student perceptions of the class’ openness to failure would change throughout the course of the class since there were failure-related activities throughout the term. Similarly, since the class is an introductory design course in the Mechanical Engineering department, it is easy to draw the connection between the failure-related experiences in the class and how they might be representative of design and Mechanical Engineering more broadly. However, it is possible that these connections are harder to make when it comes to students’ perceptions of themselves and the university at large. These impressions appear to be more immutable and seen as separate from the class experience.

Self-Efficacy and Failure Indexes

Students’ overall agreement (selecting a response of “Agree” or “Strongly Agree” with the 5 self-efficacy statements did not change consistently during the three surveys, as shown in Figure 4. Additionally, there were no consistent gender differences in responses to these answers, which is surprising as prior research shows that girls tend to have a greater fear of failure than boys, with a more significant difference amongst high-performing students [1]. This could be due to the small sample size or the virtual environment of the class.

Table 2: Statements corresponding to the self efficacy and failure indexes showing the percentages of students agreeing or strongly agreeing with each statement in this course and in the USA overall. Rows with a percentage difference of more than 10 points are highlighted.

	Statement	Avg % of students agreeing/ strongly agreeing	% of students who agreed/ strongly agreed with the statement in the USA [1]
Self-efficacy	I usually manage one way or another	96	94
	I feel proud that I have accomplished things	95	92
	I feel that I can handle many things at a time	75	74
	My belief in myself gets me through hard times	86	75
	When I’m in a difficult situation, I can usually find my way out of it	100	88
Failure	When I am failing, I worry about what others think of me	74	58
	When I am failing, I am afraid that I might not have enough talent	75	60
	When I am failing, this makes me doubt my plans for the future	60	65

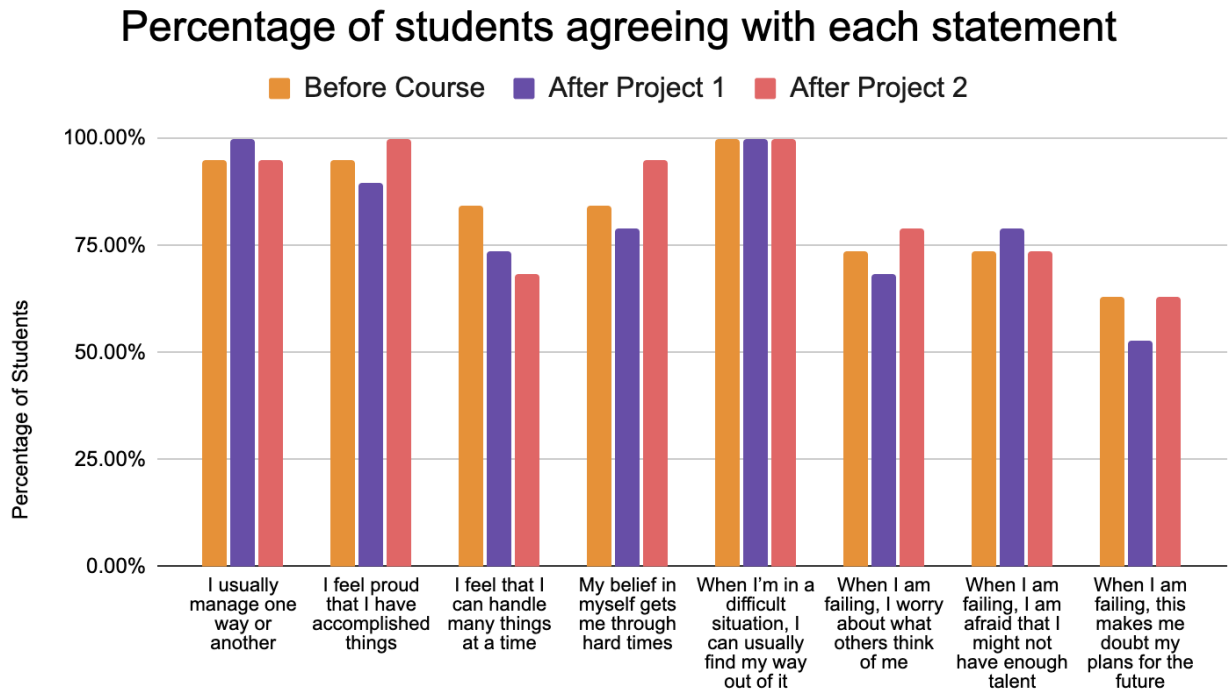


Figure 4: Percentage of students agreeing or strongly agreeing with each statement. The first 5 correspond to the self-efficacy index and the last 3 correspond to the failure index.

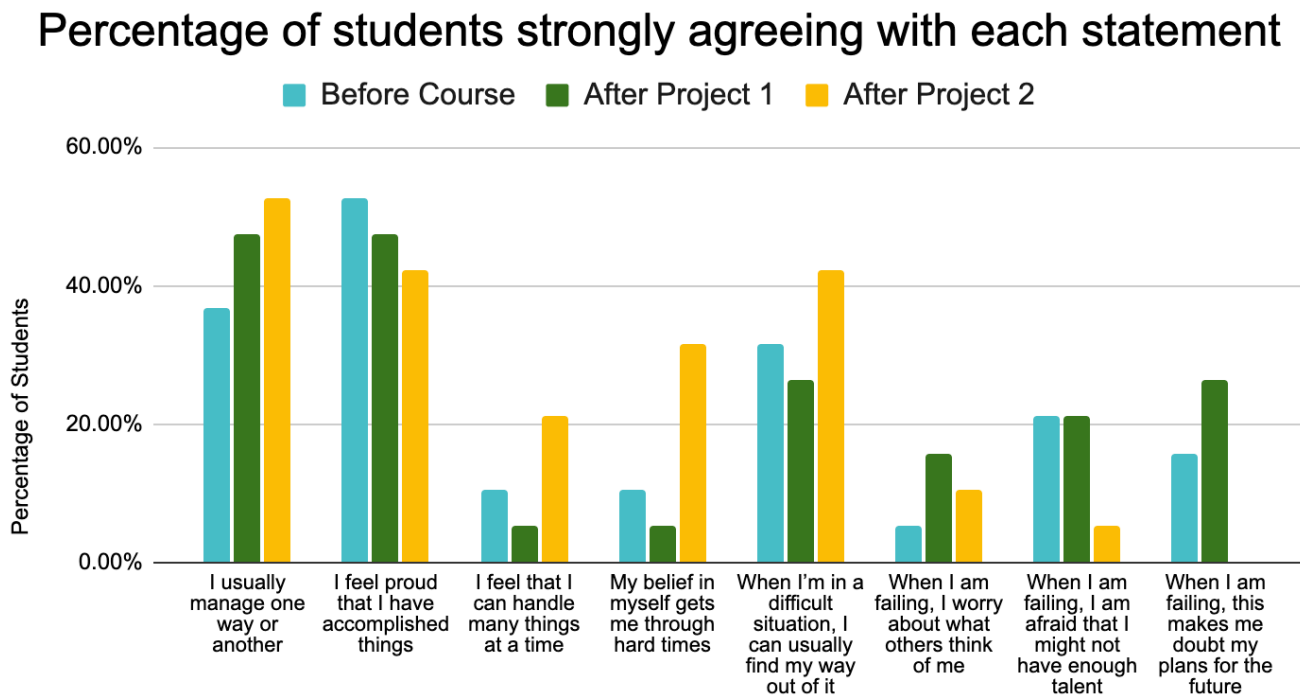


Figure 5: Percentage of students strongly agreeing with each statement. The first 5 correspond to the self-efficacy index and the last 3 correspond to the failure index.

However, as shown in Figure 5, there was a more consistent pattern in students' strong agreement (selecting a response of "Strongly Agree"). In four of the five self-efficacy metrics, students strongly agreed more at the end of the course than at the beginning or middle of the course. Similarly, in two of the three failure metrics, students strongly agreed less at the end of the course than at the beginning or middle of the course.

There were also several interesting differences between the students in this study and the OECD findings for 15-year olds in the United States as shown in Table 2 [1]. There is a slight difference in the ages of the students in the study, who were primarily college sophomores (3-5 years older than the students in the OECD study). Students in this study had responses of around 10 percentage points higher than the USA study for the following self-efficacy statements: "My belief in myself gets me through hard times" and "When I'm in a difficult situation, I can usually find my way out of it." Both of these appear to be related to grit, and it would be interesting to further investigate if there are differences in grit scores for these two populations.

Simultaneously, students in this study had responses of around 15 percentage points higher than the USA study for the following failure statements: "When I am failing, I worry about what others think of me" and "When I am failing, I am afraid that I might not have enough talent." These appear to be in line with themes of imposter syndrome and fear of disappointing others that resonated with them in the failure seminars. Further studies could help elucidate why this population of college students has much stronger agreement with these statements.

3.3 Open-Ended Student Comments on Failure-Related Course Content

Students were given the opportunity at the end of the semester to provide comments on the failure-related interventions (such as the failure seminars, mistake museum, and prototype logger) during the semester. They primarily commented on the failure seminars. Several students mentioned that the failure seminars were their favorite, with one student remarking, "I wasn't expecting the failure seminars to be that interesting, but they ended up being one of my favorite parts of the class. I was surprised at how many different perspectives each speaker had on failure." Another mentioned, "I really appreciated the failure seminars because it gave me new ways of thinking about things I've run into before."

A few students mentioned that different peoples' labels of failures influenced their perceptions. One said, "I feel like the first two failure seminars weren't real failures, and the trajectory from the failure then on was a little too cushioned. Overall, I did enjoy the failure seminars though!" Another said "I think it was hard to label stuff as 'failure' other than a failing grade. I've always been pretty optimistic, so having a setback wasn't really 'failing' for me, but when this class

kinda labeled it as such, it just made me more self-conscious rather than motivated." This was a very unique perspective, as it indicated that the mismatch in labeling of failures could be demotivating for students rather than encouraging them to embrace failure.

Students enjoyed the practical experience with failure as well. One wrote, "I think the seminars were helpful in the traditional sense of failure, which is hard to free yourself from those ideas, but confronting things head on with practice (sketching, prototyping, etc.) were also very helpful." Another mentioned that "the prototype logging caused more pressure for me but it probably made it easier for us to record our work."

Additionally, we received an unsolicited comment from a student who ran into a major problem at the end of her final project the night before it was due. She wrote, "...I just wanted to let you know how useful our failure seminars and the general discussion of failure in class has been. While I would've most likely been crying in this situation, the mindset and openness to/acceptance of failure that I developed in this class has been liberating and while I really do wish that I had been able to fix this, I'm very grateful... [for] this opportunity to fail and learn from my mistakes." This was a concrete example of the ways in which the failure-related interventions were useful to students and manifested changes in their actual behavior.

3.4 Limitations

This was a small study with a limited number of students, and meant to be a preliminary first step for other studies. Sample size limitations made it difficult to extract meaningful demographic comparisons beyond preliminary gender comparisons. Additionally, this course was conducted entirely remotely, which led to several limitations. Though it was easier to engage a variety of failure seminar speakers, it was challenging to gauge student engagement during the events as some students had their cameras off and did not speak. Our primary method of assessing the impact of these events was instead through the reflections. If this course were to run in person, we imagine student engagement during the seminars would increase and the results would be more meaningful.

4. CONCLUSIONS AND FUTURE WORK

RQ 1: *Do intentional experiences with low-stakes failure through the design process change undergraduate student attitudes towards failure?*

This study found that intentional experiences with low-stakes failure through the design process do influence some student attitudes towards failure. Students' attitudes towards failure changed with respect to their perceptions of the class, the field of design, and their major. However, their perceptions of their own openness to failure and their academic institution's openness to failure were unchanged.

RQ 2: *Do opportunities for reflection during the design process impact student perceptions of failure and propensity towards embracing failure?*

Opportunities for reflection during the design process also impacted student perceptions of failure. In particular, they especially valued hearing from speakers during the course. Students identified the reflection-intensive interventions as high impact in terms of helping them shift mindsets towards embracing failure. The study also found that asking students to record the learning outcomes from each prototype/iteration led them to reflect on personal reactions in addition to detailing the technical issues with their prototypes. The prototype logger was useful for students to consciously reflect on their prototypes and what they learned from each iteration. This regular reflection practice should be built into courses, even in person, to allow students to synthesize learning outcomes.

Future work could include evaluations of students' attitudes towards failure at different time intervals after the initial interventions to determine whether or not the impacts of the interventions are sustained. It would also be interesting to test these and other interventions at other institutions or at different points in a student's academic career. For instance, do these interventions have better impact if done in a K-12 setting, or would they be more effective during an undergraduate capstone experience? Similarly, it would be interesting to compare results between experiences with low stakes and high stakes failures. Additionally, it would be compelling to see if student attitudes in other areas outside of the academic context have been impacted. It would also be important to run these interventions with larger and more diverse sample sizes to better understand how different populations respond to the interventions. Above all, we recommend that other courses adopt reflection-intensive failure interventions.

5. ACKNOWLEDGEMENTS

We thank the students involved in the class for their participation in the course and willingness to provide feedback. Thanks to Shelly Ben-David for her work in developing the initial survey questions on student experiences with failure. This project was funded by an MIT Abdul Latif Jameel World Education Lab (J-WEL) Grant in Higher Education Innovation. Any opinions, findings, and conclusions/recommendations expressed here are those of the authors and do not necessarily reflect the views of the funders.

REFERENCES

- [1] Development, O. for E. C. and, 2020, "Students' Self-Efficacy and Fear of Failure," pp. 187–198.
- [2] Covington, M. V., and Omelich, C. L., 1981, "As Failures Mount: Affective and Cognitive Consequences of Ability Demotion in the Classroom," *J Educ Psychol*, **73**(6), pp. 796–808.
- [3] Ruble, D. N., Parsons, J. E., and Ross, J., 1976,

"Self-Evaluative Responses of Children in an Achievement Setting," *Child Dev*, **47**(4), pp. 990–997.

[4] Chase, C., 2011, "Motivating Persistence in the Face of Failure: The Impact of an Ego-Protective Buffer on Learning Choices and Outcomes in a Computer-Based Educational Game" [Online]. Available: https://stacks.stanford.edu/file/druid:yw409rc6957/Chase_Dissertation_Submitted_to_Stanford_FULL-augmented.pdf. [Accessed: 19-Jan-2021].

[5] Marks, J., and Chase, C. C., 2019, "Impact of a Prototyping Intervention on Middle School Students' Iterative Practices and Reactions to Failure," *J Eng Educ*, **108**(4), pp. 547–573.

[6] Daly, S. R., Yilmaz, S., Christian, J. L., Seifert, C. M., and Gonzalez, R., 2012, "Design Heuristics in Engineering Concept Generation."

[7] Yang, M. C., 2005, "A Study of Prototypes, Design Activity, and Design Outcome," *Design Stud*, **26**(6), pp. 649–669.

[8] Austin-Breneman, J., Honda, T., and Yang, M. C., 2012, "A Study of Student Design Team Behaviors in Complex System Design," *J Mech Design*, **134**(12), p. 4.

[9] Neeley, W. L., Lim, K., Zhu, A., and Yang, M. C., 2013, "Building Fast to Think Faster: Exploiting Rapid Prototyping to Accelerate Ideation During Early Stage Design," p. V005T06A022-V005T06A022.

[10] Kelley, T., and Littman, J., 2006, *The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate and Driving Creativity Throughout Your Organization*.

[11] Reid, K. J., and Ferguson, D. M., 2014, "Do Design Experiences in Engineering Build a 'Growth Mindset' in Students?," 2014 Ieee Integr Stem Educ Conf, pp. 1–5.

[12] Dweck, C. S., and Yeager, D. S., 2019, "Mindsets: A View From Two Eras," *Perspect Psychol Sci*, **14**(3), pp. 481–496.

[13] Vongkulluksn, V. W., Matewos, A. M., and Sinatra, G. M., 2021, "Growth Mindset Development in Design-Based Makerspace: A Longitudinal Study," *J Educ Res*, pp. 1–27.

[14] Carberry, A. R., Lee, H., and Ohland, M. W., 2010, "Measuring Engineering Design Self-Efficacy," *J Eng Educ*, **99**(1), pp. 71–79.

[15] Das, M., 2020, "Taking a Bandsaw to First Grade: Transforming Elementary School Through Hands-on STEAM Education."

[16] Reymen, I. M. M. J., and Hammer, D. K., 2002, "Structured Reflection for Improving Design Processes."

[17] Duckworth, A. L., and Quinn, P. D., 2009, "Development and Validation of the Short Grit Scale (Grit-S)," *J Pers Assess*, **91**(2), pp. 166–174.

[18] Dweck, C., 2007, *Mindset: The New Psychology of Success*.