

Mastery-Based Learning Inspires Persistence and Growth Through Failure

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1. Introduction

Failure tolerance is a necessary skill for professionals in fields demanding innovation. The ability to persist through and learn from failure has been identified as a key outcome of an entrepreneurial mindset (EM) [1]. In response, there has been significant interest in designing course structures that facilitate productive failure, particularly within entrepreneurship education, the KEEN network, and broader engineering education. One promising approach could be mastery-based learning (MBL), which may promote EM by normalizing failure and encouraging students to learn from their past mistakes [2, 3, 4]. To effectively cultivate an entrepreneurial mindset in undergraduates, students must encounter and learn to navigate obstacles at all levels of learning. Implementing MBL can provide a crucial first-step toward developing failure tolerance.

The MBL framework employed by the authors [5, 6] requires students to demonstrate mastery of fundamental skills to pass a course. Mastery is demonstrated by completing test questions with near-perfect solutions. Final grades are then based on the number and complexity of skills mastered during the semester. Unlike traditional grading systems, MBL does not award partial credit; assessments are evaluated as either *Passed* or *Not Yet*. However, students can retake assessments as needed until the course ends, allowing each failure to become a learning opportunity. This process transforms failure into a stepping stone toward mastery. Practically, the MBL framework is focused about a cyclical process of learning, testing, analyzing, and retesting, with instructors providing guidance throughout.

This paper aims to explore the relationship between MBL and EM by examining if MBL courses promote failure tolerance and growth mindset. Specifically, it will address the following research goals:

1. Assess and compare students' failure tolerance before and after completing MBL courses.
2. Analyze pre- and post-course survey responses regarding students' reactions to failure and their failure mindset.
3. Gather direct student feedback on the MBL framework through post-course surveys.

2. Methods

Pre-course and post-course surveys were conducted across five courses during the fall semester at three small, private institutions with engineering programs. Two of the institutions were located in the Midwest, while the third was in the Northeastern United States. The courses ranged from first-year introductory classes to discipline-specific junior-level courses (Table 1). Four of the courses followed a fully MBL framework initially developed at Elizabethtown College (ETOWN) [6], and adapted at Ohio Northern University (ONU) [5] and the University of Detroit Mercy (UDM). The exception was ENGR 1234, which employed a modified, partial MBL approach (Appendix 1).

Table 1: Surveyed MBL courses across three institutions.

Institution	Course	Level	Enrollment
ONU	ME 3111: Mechanical Design 1	Junior	83 (2 sections)
ETOWN	PHY 120: Introductory Mathematics for Physics and Engineers	First-year	46
UDM	ENGR 1234: Introductory Mathematics for Engineering Applications	First-year	24
UDM	ENGR 3120: Statics	Sophomore	29
UDM	ENGR 3260: Mechanics of Materials	Sophomore	7

Pre- and post-course surveys were designed to include both Likert-scale evaluations and open-ended questions (Table 2). The pre-course surveys were administered during the first week of the semester, while the post-course surveys were conducted during the final week of course meetings. Both surveys were administered with IRB approval. A total of 165 students completed the pre-course survey, and 125 students completed the post-course survey.

2.1 Research Question 1

To assess the students' failure tolerance before and after completing MBL courses, a Likert-scale failure tolerance assessment was created by adapting two existing tools [7, 8]. Students rated each question on a scale from 1 (Totally False) to 6 (Totally True), where lower scores indicated greater failure tolerance and higher scores reflected a stronger fear of failure. Each student's failure tolerance score was calculated by summing their 11 responses. Scores ranged from 11, representing complete tolerance for failure, to 66, indicating a total fear of failure, with 38.5 considered neutral. Results from all institutions were aggregated, and average scores were calculated and compared. Students were also categorized into five groups based on their scores: High Failure Tolerance (11–21), Failure Tolerance (22–32), Neutral (33–44), Fear of Failure (45–55), and High Fear of Failure (56–66).

At ONU, individual student responses were tracked to measure changes in scores over the semester. A total of 72 students at ONU completed both the pre- and post-course surveys.

Table 2: Questions on pre-course and post-course surveys.

	Questions	Pre-Course	Post-Course	Research Question
Likert Failure Tolerance Assessment	1. In general, I prefer to work on a puzzle that I know I can complete rather than try to do a puzzle that might be too hard for me.	x	x	1
	2. If I do poorly on something, I usually prefer to not let anyone else know or try to cover it up.	x	x	1
	3. I sometimes find myself carelessly doing things I find difficult.	x	x	1
	4. When I compete with someone who seems to be better than I am, I sort of give up trying.	x	x	1
	5. Sometimes when others are talking about their accomplishments, I find myself exaggerating things I have done in the past.	x	x	1
	6. I usually avoid telling a joke in public because people might not laugh.	x	x	1
	7. Experiencing failure inhibits my learning and growth.	x	x	1
	8. When I do something particularly well, I usually let my family and friends know.	x	x	1
	9. Experiencing failure hinders my future performance and productivity.	x	x	1
	10. There are times when I worry about being successful in my career	x	x	1
	11. When I feel uncertain about how I might perform compared to others in an activity, I prefer to watch rather than participate.	x	x	1
Open-ended	12. How do you react to and handle failure?	x	x	2
	13. How would you define a healthy mindset toward failure?	x	x	2
	14. What was the most positive aspect of mastery-based assessments?		x	3
	15. What was the most negative aspect of mastery-based assessments?		x	3
	16. How has this semester changed your failure mindset thinking?		x	3

2.2 Research Question 2

Two open-ended questions were included in both the pre-course and post-course surveys to collect and evaluate the students' reactions to failure and their failure mindset before and after taking an MBL course (Table 2). Thematic similarities and differences between the responses were analyzed using ChatGPT [9, 10]. The full set of student responses was submitted, and the AI was prompted to compare and quantify changes between the two datasets. The AI also identified student quotes to support its findings.

2.3 Research Question 3

To gather direct student feedback on the MBL framework, three questions were asked exclusively in the post-course survey (Table 2). Responses to these questions were manually coded into common themes for further analysis.

3. Results

3.1 Likert Failure Tolerance Assessment

Failure tolerance assessment scores were pooled across the three institutions. Pre-course survey data showed that students entered the courses with a slight tolerance for failure, reflected in an average score of 32.0 ± 7.52 (Fig. 1A). Post-course surveys revealed no significant change in the average failure tolerance score ($p = 0.96$), which remained at 32.0 ± 7.09 . A majority of students were categorized as failure tolerant or better on both the pre-course (56.8%) and post-course (60.8%) surveys (Fig. 1B). Notably, only one student scored in the high fear of failure category across both surveys.

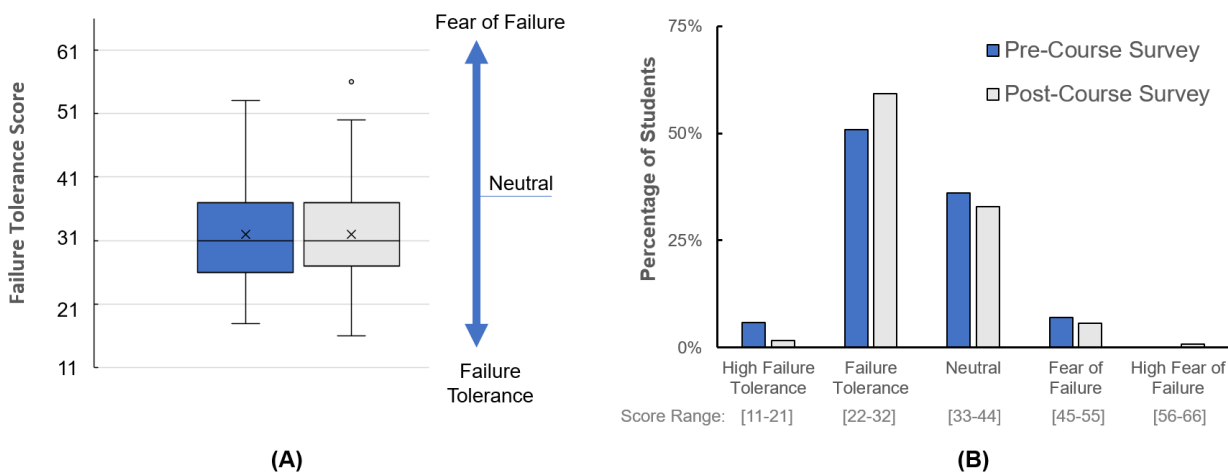


Figure 1: (A) Failure tolerance assessment scores showed no difference between pre-course ($n = 169$) and post-course ($n = 125$) surveys. (B) For both datasets, the majority of students scored as failure tolerant with scores ranging from 22-32. $p = 0.96$; student's *T*-test

Tracking and comparing individual responses at ONU revealed a slight average decrease in failure tolerance following MBL course completion: -0.93 ± 3.95 (Fig. 2A; $p < 0.05$, paired *t*-test). The majority of students ($n = 42$; 58.7%) recorded changes within one standard deviation of no change, indicating their scores shifted only slightly, either toward more or less tolerant (Fig. 2B). Overall, 25 students (34.7%) improved their failure tolerance scores, while 43 students (59.7%) became less tolerant. Additionally, four students (5.6%) scored the same on both the pre- and post-course surveys.

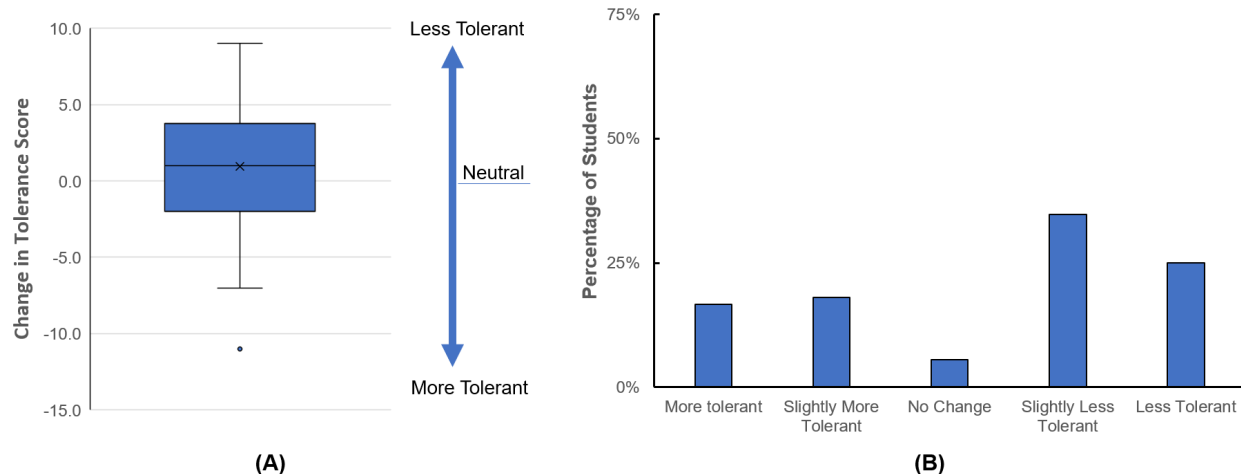


Figure 2: (A) Changes to failure tolerance score for individual students at ONU. On average, students scored slightly less tolerant on the post-course survey. (B) The distribution of changes to failure tolerance scores between pre- and post-course surveys. Students scoring within one standard deviation from zero (no change) were binned into the slightly more or slightly less tolerant groups.

3.2 Comparison of open-ended student responses between pre-course and post-course surveys

AI tools were used to categorize differences between pre- and post-course responses to the question, “How do you react to and handle failure?” The AI tool identified six primary areas of comparison:

1. View of failure as a learning opportunity
2. Emotional reactions to failure
3. Coping mechanisms
4. Mindset toward failure
5. Dependency on context
6. Resilience and Perseverance.

Responses to both surveys highlighted a common recognition of failure as a learning opportunity. However, pre-course survey responses were more likely to be generalized or vague. Post-course responses tended to be more specific and nuanced, emphasizing personal experiences with failure. Additionally, emotional reactions to failure were often more prominently described in post-course responses and often accompanied by coping mechanisms students used to manage these feelings. Finally, while pre-course responses frequently portrayed learning from failure as a passive trait, post-course responses were more likely to frame it as an active process, supported by deliberate reflection and personal growth. These results, along with example quotes, are summarized in Table 3. The full AI output is included in Appendix 2.

Table 3: Summary of AI comparison of pre- and post-course responses to “How do you react to and handle failure?” [9]

Aspect	Pre-course	Post-course
View of Failure	Abstract <i>“Failure is part of success.”</i>	Personal and actionable <i>“I take time to reflect on what I did wrong and analyze my mistakes.”</i>
Emotional Awareness	Limited; emotions not often mentioned <i>“Just keep going”</i>	Rich; emotions like guilt, anger, and sadness are addressed. <i>“I feel guilt and anger at first, then reflect”</i>
Coping Mechanisms	Vague <i>“Learn from it.”</i>	Specific <i>“Take a break and then reflect.”</i>
Mindset	Focused on external ideas about failure <i>“You can’t succeed without Failure”</i>	Focused on internal, personal experiences of failure <i>“I don’t let failure define me”</i>
Context Sensitivity	One-size-fits-all approach <i>“Failure is failure, and you just have to get back up.”</i>	Nuanced; reactions vary depending on the situation. <i>“If it’s a repeated failure, I get upset.”</i>
Resilience	Passive <i>“Don’t give up.”</i>	Active <i>“I reflect and create a plan to improve.”</i>

AI tools were also used to analyze differences between pre- and post-course responses to the question, “How do you define a healthy mindset toward failure?” The results, along with example quotes, are summarized in Table 4. The full AI output is included in Appendix 3. Four main themes emerged with increased prominence in post-course responses:

1. A stronger focus on growth and learning, often accompanied by more detailed and specific strategies.
2. An emotional shift toward viewing failure as a positive and essential component of personal growth.
3. A clearer articulation of resilience, emphasizing problem-solving and sustained motivation.
4. Responses that demonstrated greater depth and reflection, showcasing an enhanced ability to analyze and learn from failure.

Table 4: Summary of ChatGPT comparison of pre-course and post-course responses to “How would you define a healthy mindset toward failure?”

Theme	Pre-Course (%)	Post-Course (%)	Change (%)	Example Pre-Course Response	Example Post-Course Response
Focus on Growth & Learning	45%	72%	27%	"Learning from failure and trying again."	"By viewing it as a steppingstone to fully learning and understanding the content. You did not learn to walk on your first try, but instead, you adjusted and learned how to not fall."
Emotional Shift	22%	50%	28%	"Not letting failure make you feel bad."	"You should embrace failure as a part of life and see it as a chance to get better at something."
Resilience & Persistence	28%	60%	32%	"Not giving up when you fail."	"After failing, you learn what you missed, fix it, and then you don't fail anymore."
Conceptual Depth	10%	40%	30%	"Trying to see what went wrong."	"Analyzing failure deeply to understand and grow from it."

3.3 Exclusive post-course survey questions

Manual coding was used to analyze student responses to three questions included only in the post-course surveys. Additional example quotes for each category are provided in Appendix 2.

A summary of responses to the question, “What was the most positive aspect of the mastery-based assessments?” is shown in Figure 3. Some responses were categorized under multiple themes. The most frequent response (n = 35) highlighted how MBL assessments fostered deeper learning and understanding compared to traditional courses:

“I got to fully understand the concept that I was being tested on instead of doing it, then being done after the test. This allowed me to fully comprehend and understand the material instead of just memorizing it.”

“I could learn from mistakes since I had to get a problem perfect. This let me really learn the topics rather than pass by with a low grade”

The second most common theme (n = 34) was the creation of a safe space to fail and learn from mistakes:

“There felt like less consequence for making mistakes, which allowed me to focus on learning the content and trying the problem than just memorizing to ‘not fail’.”

“It allows for large failures at the beginning of the class to be setbacks toward your goal grade (A, B, C etc.). It's not like a normal class where a 30% on the first exam could totally ruin your

grade for the rest of the semester. By the end of the class, I feel that Mastery-Based assessments more accurately depict my knowledge of the subject than the average class does.”

Many students (n = 24) specifically praised the opportunity to retake assessments as the most positive aspect. While these responses often overlapped with themes of learning from failure or deeper understanding, they were coded separately if they focused solely on the retake policy:

“You get multiple attempts to get it right”

“There is always another chance to get it right the next week unless you run out of weeks.”

Finally, a reduction to stress and anxiety associated with test taking was a notable benefit for many students (n = 20).

“It means I am not as distraught when I fail and I can keep trying. Having a one and done failure really effects my mental health. In the end I actually learn the skills I passed better because I have to keep working at them until I succeed.”

“Without the worry of grades, it made me want to actually try my best I could and not worry about the possibility of failure.”

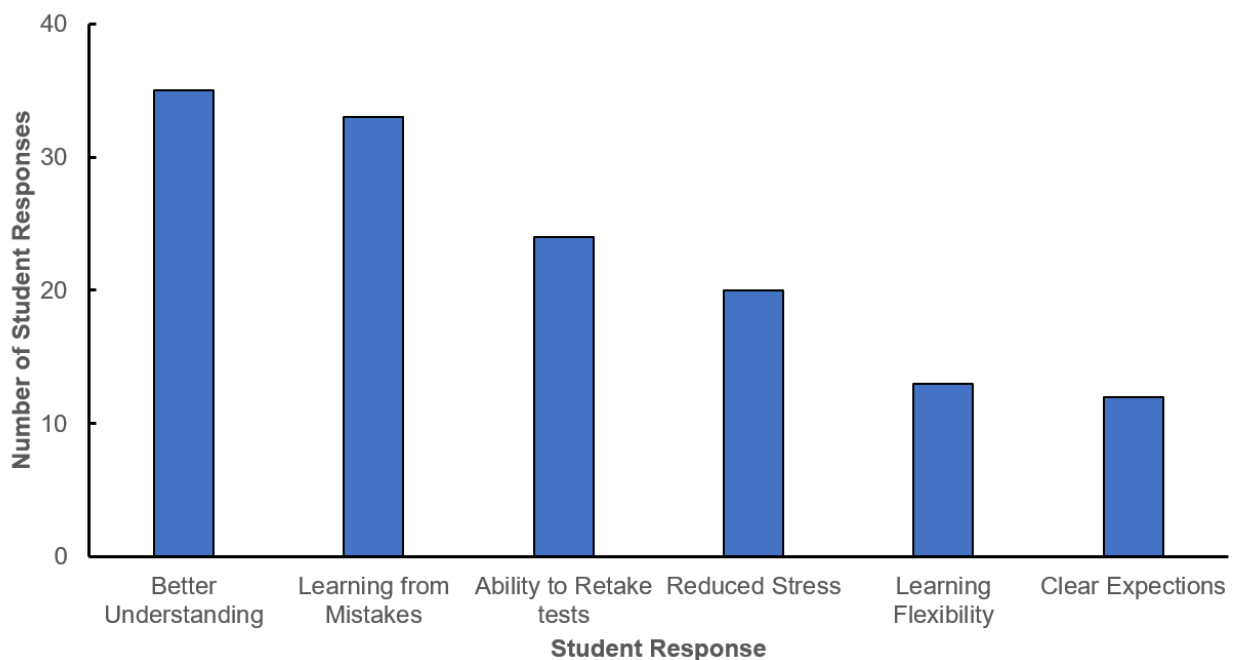


Figure 3: Student responses (n = 115) to “What was the most positive aspect of the Mastery-based assessments?”

Student opinions on the negative aspects of MBL were also manually coded (Fig. 4). While 115 students completed the post-course survey, only 98 students addressed at least one negative aspect of the course. The most frequent theme (56.1%) was related to the weekly assessment tests, which were associated with the following three trends:

- **No Partial Credit:** *"Having to get the problem basically 100% correct, like if you would have taken the problem in an exam setting you woulda got 85% right then moved on, where with the tests if you got an 80% you failed and had to start over and repeat that test."*
- **Frustration from repeated Failure:** *"The most negative aspect of these assessments was that failing multiple times in a row could lead to not wanting to attempt the test again."*
- **Difficult test with new questions each week:** *"Sometimes it was annoying because I knew how to do the problem and understood the concept, but then I would get thrown off by a simple difference, for example, a slightly different configuration of a linkage and then I wouldn't pass the skill even though I knew how to do it."*

An additional 27.6% of responses were related to the pacing of the course, with students mentioning struggles to complete assessments on time and concerns about falling behind other students:

- **Pacing and self-motivation:** *"One thing I did not like is that I oftentimes did not feel motivated to study because I knew it was not the end of the world if I got one wrong."*
- **Perception of falling behind peers:** *"The greatest negative was understanding that I was behind and had to do quite a bit of extra work than my peers to be on the same level."*

Finally, 16.3% of responses focused on issues related to the organization of the course, including aspects unrelated to the MBL framework.

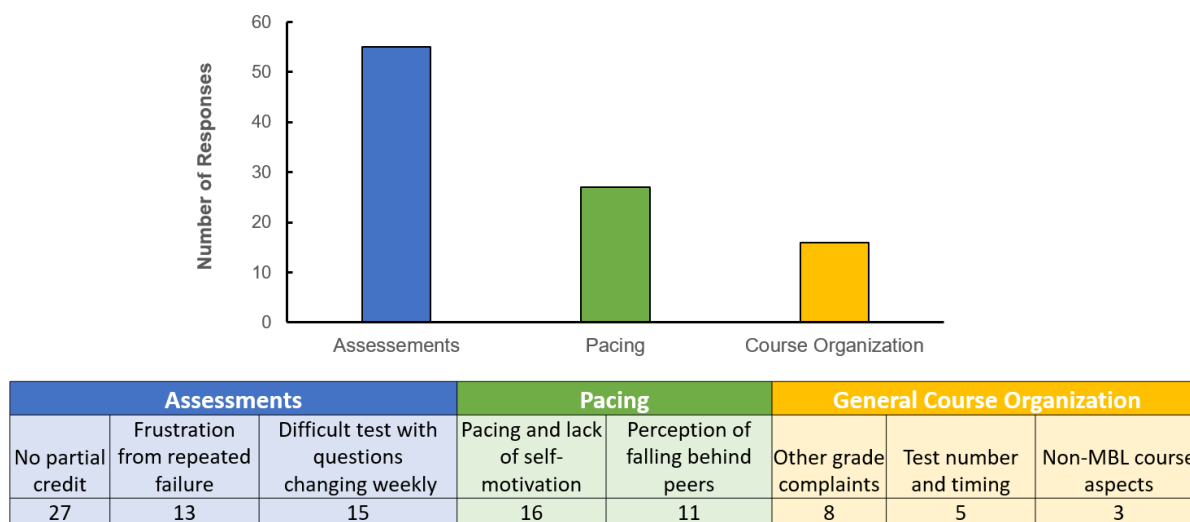


Figure 4: Student responses (n = 98) to "What was the most negative aspect of the Mastery-based assessments?"

Lastly, students were asked, "How has this semester changed your failure mindset?" Overall, 66% of students reported a positive shift in how they viewed failure (Fig. 5). These positive changes were associated with three primary response trends. First, 27 students (27.6%) described how failure in the course motivated changes in their behavior or work ethic:

"It has taught me to ask more questions when I am struggling to figure something out instead of sitting around doing the same thing over and over."

"It has showed me that using failure as motivation can help future attempts rather than give up and hurt future attempts."

Second, 19 students (19.4%) adopted a growth mindset, seeing failure as an opportunity to learn:

"It has helped be to think of failure better since every time I would not get the score I wanted I always was able to look at what I did wrong, learn from it, then always do better the next time even if it was by a little."

"It has allowed me to realize failure is not the end of the world and I can use it to get better at certain things."

Finally, 28 students (28.6%) expressed a greater acceptance of failure and increased resilience:

"This semester has definitely made me more resilient to failure in general, I feel that I will respond to failure in a much healthier way than I used to. I have a better understanding of how to also balance failures with successes, and that failures are to be expected and embraced."

"I do not feel as bad when I fail because I realized that I might just need some more time than others to be successful but I CAN actually be successful if I continue to try."

A total of 34 students (34.7%) reported no change in their failure mindset. These comments either reflected a pre-existing tolerance for failure or were not elaborated upon.

"It hasn't really changed my mindset"

"It hasn't changed my mindset very much, I had a pretty good outlook on failure before this class."

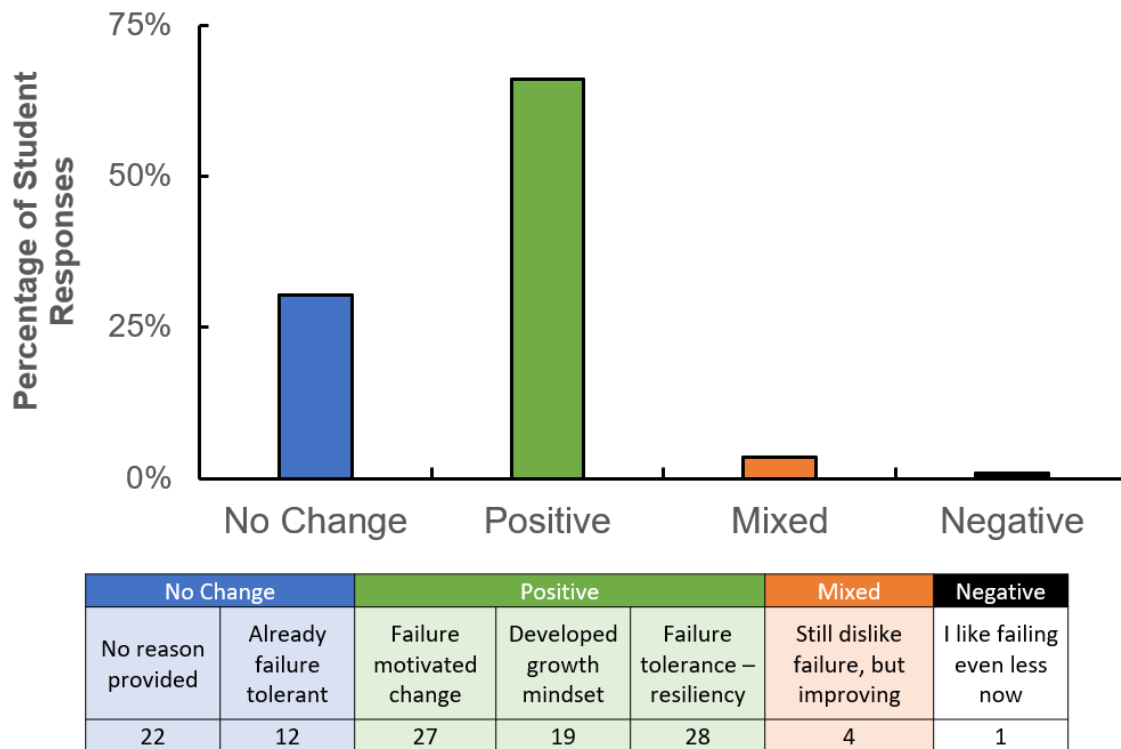


Figure 5: Student responses to “How has this semester changed your failure mindset thinking?” Overall, 66% of students reported a positive change in how they viewed failure.

Discussion

The goal of this paper was to establish a connection between the mastery-based learning (MBL) framework and the development of an entrepreneurial mindset (EM) in engineering students. Open-ended responses from post-course surveys revealed that students overwhelmingly believed a semester in an MBL course positively influenced their mindset toward failure (Fig. 5). Many students also highlighted that the opportunity to learn from past mistakes was the most beneficial aspect of the course (Fig. 3). A comparison of open-ended responses from pre- and post-course surveys showed a notable shift in how students described failure, with more positive perspectives emerging from the post-course surveys (Table 4). Students also demonstrated an improved ability to articulate specific strategies for learning from and persisting through failure on post-course surveys (Table 3). Overall, this paper is among the first to provide evidence of a connection between MBL and EM development across multiple institutions. These findings align well with preliminary studies conducted at ONU [5] and ETOWN [10].

While open-ended responses demonstrated a clear connection between MBL and EM development, the Likert-scale failure tolerance assessment showed no significant change between pre- and post-course surveys (Fig. 1). This outcome is consistent with findings with previous work [10] utilizing a similar type of assessment and similarly found no measurable change. One possible explanation is that the assessment includes too many questions addressing varied aspects of fear of failure, potentially diluting its effectiveness. A deeper analysis of the individual assessment questions may be necessary to better understand how MBL course effect specific dimensions of failure tolerance.

A decrease in failure tolerance for paired survey results at ONU was another surprising result (Fig. 2). One possible explanation is that students became more aware of their own reactions to failure by the end of the semester, having experienced it multiple times through the MBL framework. Similarly, some students likely overestimated their failure tolerance at the beginning of the semester. This interpretation is supported from some student post-course responses:

"I've realized that I'm not as good at handling failure as I thought I was at the beginning of the semester. I've learned a lot about myself when it comes to failure, and I am trying to perfect my healthy mindset towards failure."

Additionally, the fall semester of junior year is notoriously the most academically challenging at ONU, meaning students' responses were likely influenced by their overall course load and extracurricular activities, not just the MBL course. Taken together, these factors highlight the complexity of assessing mindset changes during a semester. Future work should employ similar surveys in non-MBL courses to provide a control group to compare with.

This paper utilized AI tools to analyze similarities and differences in pre- and post-course survey responses. AI tools are particularly effective in managing large datasets and minimizing the impact of author bias when coding responses [11]. However, a notable disadvantage of using AI is the lack of transparency in how it categorizes specific responses. Additionally, the trends identified by AI do not necessarily indicate changes caused by MBL but may instead reflect that students have more relevant examples to share about failure at the end of the semester compared to after summer break. Nevertheless, the results demonstrate that students are better able to reflect on past experiences of failure by the conclusion of the course.

Failure during the undergraduate curriculum is often a crucial first step toward future success. Of course, failure in a technical math or science course is not the same as failing during entrepreneurial venture. In the former, most questions have one correct solution, whereas the "correct" course of action is much more nebulous. However, experiencing failure in technical courses can still cultivate an entrepreneurial mindset by encouraging problem-solving, adaptability, and perseverance in the face of uncertainty, while also developing resilience, humility, and grit. Persistence through failure is only productive when students can effectively learn from their mistakes [12, 13]. This study demonstrated that the MBL framework creates a safe environment where students can learn from their errors and grow. In contrast, the high-stakes assessments typical of traditional courses often deprive students of opportunities to practice productive failure or demonstrate their ability to learn from past mistakes. One student survey response highlighted the challenge of applying their new appreciation for failure in other courses:

"This course actually did help me to realize the power of failing, if handled correctly. Incorporating this mindset into future courses may be more tricky since exams with no re-dos are higher stakes, but I can still apply it to homework and in-class assignments."

To foster an environment where failure is a safe and valuable learning experience, motivate students to learn from their setbacks, and equip them with skills for success, instructors are encouraged to explore and adapt mastery-based learning in their courses.

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Appendix 1: Use of MBL in three courses at the University of Detroit Mercy (UDM)

Term Fall: 2024-25

ENGR 3120: Statics (Number of Students: 29)

This is the first time MBL grading was used for Statics at UDM. The structure of the class was modeled using the approach similar to ETOWN. The content was divided into Primary, Required and Supplemental skills.

Skills Passed	Grade	Skill Topics
Pass any 1 P skill	F	P1 – 2D Forces
Pass any 2 P skills	D-	P2 – 2D Moments
Pass any 3 P skills	D	P3- 2D Free Body Diagrams
Pass any 4 P skills	D+	P4- 2D Equations of Equilibrium
		(must pass all P skills to earn credits for R skills)
Pass any 1 R skill	C-	R1 – Distributed Forces
Pass any 2 R skills	C	R2 - Beams
Pass all 3 R skills	C+	R3 - Trusses
		(must pass all R skills to earn credit for S skills)
Pass any 1 S skill	B-	S1 - Friction
Pass any 2 S skills	B	S2 – Centroid and Moment of Inertia
Pass any 3 S skills	B+	S3 – 3D Analysis
Pass any 4 S skills	A-	S4 – Frames and Machines
Pass any 5 S skills	A	S5 – Design Project

Students earned their grade (or demonstrated mastery) by correctly solving a problem on the topic in an exam setting. Students got two possible grades/feedback to any attempt: Not yet or Completed. HWs were assigned but were graded for completion. Those who finished over 70% of all assigned HW received 1/3 of a grade boost. Class meeting times were used for lecture and coaching. There were four scheduled testing opportunities (tests) and a final exam (the final opportunity). On top of this every Friday students had the opportunity to re-test by signing up for specific topics.

ENGR 3260: Mechanics of Materials (Number of Students: 7)

This is the fourth time MBL was used for this course. The content of this course was divided into 11 primary and 9 Mastery level topics spanning five core areas:

Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Axial loads	Torsion	Bending and Flexure	Buckling of Columns	Stress Transformation
Skills: Solve for Normal stresses in axially loaded members (P1) Solve for Axial Strains and deflection in Axially loaded members (P2) Shear loaded members (P3) Solve statically indeterminate problems for reaction forces and stresses (M1) Solve problems with Temperature effects (M2)	Skills: Able to draw Torque Diagrams(P4) Calculate the shear stress(P5) Calculate angular deflection(P6) Solve Statically Indeterminate problems(M3)	Skills: Calculate Moment of Inertia (P7) Draw Shear and Bending Moment Diagram(P8) Calculate Normal Stresses in Bending (P9) Calculate Shear Stresses in Beams (P10) Use Singularity Function to calculate deflection(M4) Use Superposition to Calculate deflection(M5)	Skills: Euler's Equation to calculate buckling of long columns for various end conditions (M6) Code equation to calculate buckling of medium and long columns (M7)	Skills: Apply Stress Transformation Equation to calculate Normal and Shear Stresses in any direction (P11) Calculate Principal Stresses and Maximum Shear Stress (M8) Use Mohr's circle to calculate Normal and Shear stresses (M9)

And the grades were earned by demonstrating mastery as outlined in the following table:

Grade Table Associated with Achieved Skills

Achieved Skill Level	Course Grade
Three P level requirements	D
Six P-level requirements	D+
Nine P- level requirements	C-
Ten P- level requirements	C
Eleven P- level requirements	C+
All Ps + M1, M2, M3	B-
All Ps + M1, M2, M3, M4	B
All Ps + M1, M2, M3, M4, M5,	B+

All Ps + M1, M2, M3, M4, M5, M8, M9	A-
All Ps + M1, M2, M3, M4, M5, M6, M7, M8, M9	A

Students earned their grade (or demonstrated mastery) by correctly solving a problem on the topic in an exam setting. Students got two possible grades/feedback to any attempt: Not yet or Completed. HWs were assigned but were graded for completion. Those who finished over 70% of all assigned HW received 1/3 of a grade boost. Class meeting times were used for lecture and coverage of material. There were four scheduled testing opportunities (tests) and a final exam (the final opportunity). On top of this students were able to re-test by signing up for specific topics and setting up times with instructor (there were 7 students so this approach worked because of small class size).

ENGR 1234: Introductory Mathematics for Engineering Applications (Number of Students: 24)

While the other two classes were full-fledged MBL, I like to say this course uses semi-MBL. The course grade had a traditional distribution:

Homework Assignment	10
Quizzes	15
Class Test 1	20
Class Test 2	25
Final Exam	30

In the three tests (2 class tests and the final) students earn partial grades in the questions in these exams. The first two class tests have 6 questions on 6 topics each. In the final there are 5 questions on 5 topics. For the two class tests students get the opportunity to earn better grades on those topics in the following way: (a) they have a window of time between the first test and the second test to earn a better grade by re-testing on any of the topics of that test. During this window they can re-test as many times as they want, (b) In the re-testing attempt they get to solve a similar but a different problem on each topic, (c) in the re-testing attempt they have to get the entire problem correct in order to earn points and get their grades to be replaced, (d) there is no partial grading in re-tests. In this approach, students can improve their scores on 45% of the total grade. However, this opportunity does not exist for the topics on the final.

Appendix 2 – AI Trends for How do you react to and handle failure?

ChatGPT inputs:

- I am going to upload two sets of data. Students were given a survey before taking a course and again afterwards. Here are their responses from the pre-course survey for the question "How do you react to and handle failure?" Let's call this data set pre_reaction
- *Uploaded survey response table*
- Here is the data from the post-course survey. Let's call it post_reaction
- *Uploaded survey response table*
- Can you compare the two data sets and provide examples of student comments?

ChatGPT Output Result:

Key Areas of Comparison

1. View of Failure as a Learning Opportunity

- **Pre-course:** Many participants already showed an inclination to see failure as a learning opportunity, though the phrasing often lacked depth or personal examples.
 - Examples: *"Failure is part of success,"* or *"Failure helps you grow."*
- **Post-course:** There is a stronger emphasis on personal strategies for learning from failure, indicating participants have internalized this concept more deeply.
 - Examples: *"I analyze my mistakes,"* *"I use failure to motivate myself,"* and *"I take time to reflect on what I did wrong."*

Trend: Participants shifted from general or abstract ideas about failure to specific, actionable ways they process and learn from it. This suggests growth in applying a growth mindset to real-life situations.

2. Emotional Reactions to Failure

- **Pre-course:** Initial reactions were not a primary focus, with most responses centered on how people *should* view failure rather than how they actually feel about it.
 - Examples: *"Don't let it discourage you,"* or *"Just keep going."*
- **Post-course:** Emotional responses are much more prominent, reflecting a deeper understanding of how failure feels and how it's managed.
 - Examples: *"I feel guilt and anger at first, then reflect,"* *"I get upset but try again,"* and *"I try to not let it consume me."*

Trend: The post-survey reflects a greater self-awareness of the emotional impact of failure and the strategies used to overcome these feelings.

3. Coping Mechanisms

- **Pre-course:** Few participants mentioned specific coping mechanisms. Responses were often vague or overly positive, such as *"You have to keep going,"* or *"Learn from it and move on."*
- **Post-course:** There is a notable increase in actionable coping mechanisms, such as:
 - Analyzing mistakes.
 - Using humor to ease disappointment.
 - Taking a break before revisiting the problem.
 - Seeking feedback from others.

Trend: Post-survey responses indicate participants are better equipped with tools and strategies to process failure constructively.

4. Mindset Toward Failure

- **Pre-course:** Responses often focused on failure as an external concept, with phrases like *"It's necessary for success,"* or *"You can't succeed without failing."*
- **Post-course:** There's a shift toward viewing failure as a personal experience, with more emphasis on internal reflection and growth.
 - Examples: *"I use failure as motivation,"* *"I don't let failure define me,"* and *"I try to take it as a learning experience."*

Trend: Participants moved from a theoretical understanding of failure to a more practical, self-focused application.

5. Dependency on Context

- **Pre-course:** Contextual responses were rare, with most participants expressing a one-size-fits-all approach to failure.
 - Example: *"Failure is failure, and you just have to get back up."*
- **Post-course:** Many participants noted that their reaction depends on the type or severity of failure, reflecting a more nuanced understanding.
 - Example: *"If it's a repeated failure, I get upset,"* or *"I react differently depending on whether it was in my control or not."*

Trend: The post-survey data suggests a more sophisticated understanding of failure, where participants recognize that reactions and coping strategies may vary based on the situation.

6. Resilience and Perseverance

- **Pre-course:** Many participants highlighted the importance of perseverance, with responses like *"Keep going no matter what,"* or *"Don't give up."*

- **Post-course:** While perseverance remains a common theme, the focus has shifted to building resilience through deliberate actions and mindset shifts.
 - Examples: *"I use failure as motivation," "I take time to reflect before trying again,"* and *"I focus on what's in my control."*

Trend: Perseverance has evolved from a passive trait to an active process supported by reflection and learning.

Appendix 3 – AI Trends for “How would you define a healthy mindset toward failure?”

ChatGPT inputs:

- Let’s do this for another survey question: "How do you define a healthy mindset toward failure?" Let's call this data set pre_health
- *Uploaded survey response table*
- Here is the data from the post-course survey. Let's call it post_health
- *Uploaded survey response table*
- Can you compare the two data sets and provide examples of student comments?
- Could you quantify the prevalence of each theme in the datasets?

ChatGPT output

Comparison: Definitions of a Healthy Mindset Toward Failure with Example Responses

1. Focus on Growth and Learning:

- **Pre-Course:** Students often recognized that failure was an opportunity to learn but expressed this idea simply.
Example:
 - "You should use it as an opportunity to grow and learn from mistakes."
 - "By viewing it as a steppingstone to fully learning and understanding the content."
- **Post-Course:** Growth was still a dominant theme but articulated with more depth, incorporating specific strategies for learning from failure.
Example:
 - "By viewing it as a steppingstone to fully learning and understanding the content. You did not learn to walk on your first try, but instead, you adjusted and learned how to not fall."
 - "Failure is good. Embrace it."

2. Emotional Shift:

- **Pre-Course:** Responses sometimes acknowledged negative emotions or the struggle to manage failure.
Example:
 - "Not letting it ruin your day."
 - "You should take it in stride and try to learn from it."
- **Post-Course:** Students moved toward seeing failure as a positive, essential part of growth, with less emphasis on emotional difficulties.
Example:
 - "Failure is not the end of the world; it's one of the best ways to learn."
 - "You should embrace failure as a part of life and see it as a chance to get better at something."

3. Resilience and Persistence:

- **Pre-Course:** Resilience was mentioned but often in general terms.
Example:
 - "Not giving up after you fail."
 - "To try again and not give up."
- **Post-Course:** Students described resilience in more actionable terms, with a clearer focus on problem-solving and motivation.
Example:
 - "After failing, you learn what you missed, fix it, and then you don't fail anymore."
 - "Use any unhappiness as motivation to not feel that way again."

4. Conceptual Depth:

- **Pre-Course:** Responses were shorter, with less nuance, focusing primarily on the surface benefits of failure.
Example:
 - "It's an opportunity to learn."
 - "Learn from it and move on."
- **Post-Course:** Definitions became richer and more reflective, often incorporating analogies, broader perspectives, and emotional balance.
Example:
 - "Failure is only the next step to success."
 - "Understanding that failure isn't the end of the world and that it's helpful for growth."

Key Examples of Evolution in Responses

1. **Pre-Course:**
 - "Take constructive feedback as a learning opportunity."
 - "A healthy mindset is one that motivates you after failure."
2. **Post-Course:**
 - "A healthy mindset would be one where you analyze the failure and turn it into a chance to grow. It's not just about moving on but understanding and evolving from it."
 - "Failure should be viewed as a step in the learning process. Like learning to walk, you fail at first but then adjust and succeed."

Key Takeaway:

The post-course responses show **greater depth, positivity, and actionable insights**, indicating that the course helped students develop a more reflective and constructive approach to failure. Let me know if you'd like additional analysis or visualizations!

Appendix 4: Example student quotes from post course survey.

1. What was the most positive aspect of the Mastery-based assessments?

Fostered deeper learning and understanding:

- *I got to fully understand the concept that I was being tested on instead of doing it, then being done after the test. This allowed me to fully comprehend and understand the material instead of just memorizing it.*
- *I could learn from mistakes since I had to get a problem perfect. This let me really learn the topics rather than pass by with a low grade*
- *It made me start to go to office hours and I started to learn the material better from doing that*

Creation of a safe space to fail and learn from mistakes:

- *There felt like less consequence for making mistakes, which allowed me to focus on learning the content and trying the problem than just memorizing to 'not fail'.*
- *It allows for large failures at the beginning of the class to be setbacks toward your goal grade (A, B, C etc.). It's not like a normal class where a 30% on the first exam could totally ruin your grade for the rest of the semester. By the end of the class, I feel that Mastery-Based assessments more accurately depict my knowledge of the subject than the average class does.*
- *You can fail and learn instead of just failing.*

Ability to retake tests:

- *You get multiple attempts to get it right*
- *There is always another chance to get it right the next week unless you run out of weeks.*

Reduced testing Stress and Anxiety:

- *It means I am not as distraught when I fail and I can keep trying. Having a one and done failure really effects my mental health. In the end I actually learn the skills I passed better because I have to keep working at them until I succeed.*
- *Without the worry of grades, it made me want to actually try my best I could and not worry about the possibility of failure.*
- *It also helped with the anxiety of an exam where there is only one chance and multiple topics at once.*

Learning Flexibility:

- *I liked the flexibility of it and being able to focus on what tests I wanted to take and go at my own pace. There were some Friday's where I had other exams that I would not be able to retry later on, so I would not prioritize Mech Design as much*
- *Finishing early and having that reward of no tests at the end after working really hard at the beginning of the semester.*

Clear Expectations

- *I really liked how they were individual types of problems that we were aware of before we took the assessments.*
- *You knew exactly what you were going to be tested on and can be more prepared.*

2. What was the most negative aspect of the course?

Comments regarding the assessment tests:

- No Partial Credit:
 - *Having to get the problem basically 100% correct, like if you would have taken the problem in an exam setting you woulda got 85% right then moved on, where with the tests if you got an 80% you failed and had to start over and repeat that test.*
 - *Having to get 100% on each assessment.*
 - *The most negative aspects were the accidental mistakes that we made on our tests and the continuous retaking.*
- Frustration from repeated Failure:
 - *The most negative aspect of these assessments was that failing multiple times in a row could lead to not wanting to attempt the test again.*
 - *When I got stuck on some of the tests, it was frustrating knowing I had to do it again next week.*
 - *When you try to re-take multiple tests and fail them all, it feels a lot worse than failing just one.*
- Difficult test with new questions each week:
 - *Sometimes it was annoying because I knew how to do the problem and understood the concept, but then I would get thrown off by a simple difference, for example, a slightly different configuration of a linkage and then I wouldn't pass the skill even though I knew how to do it.*
 - *I feel that each week you don't pass the tests seem to get harder the next time*

Comments regarding self-motivation and pacing:

- Pacing and self-motivation
 - *One thing I did not like is that I oftentimes did not feel motivated to study because I knew it was not the end of the world if I got one wrong.*
 - *it didn't make me study as hard as I maybe should've knowing I had multiple tries*
 - *It requires some self-organization and planning to ensure that I'd have enough attempts at each of the required skills.*
- Perception of falling behind peers
 - *The greatest negative was understanding that I was behind and had to do quite a bit of extra work than my peers to be on the same level*
 - *being out of order with other people in terms of testing which could isolate you from study groups if you were not at their pace.*

Comments regarding course organization:

- Other grade complaints
 - *Achieving an A was very difficult*
- Test number and timing
 - *I wish the some of the tests were available closer to when we learned it*
 - *I would have liked more opportunities to test on the final few topics. We got 2 chances.*
- Non-MBL course aspects
 - *I feel there could have been more in person teaching*

3. How has this Semester changed your failure mindset thinking?

Positive Changes:

- Failure in the course motivated changes in their behavior or work ethic:
 - *It has taught me to ask more questions when I am struggling to figure something out instead of sitting around doing the same thing over and over.*
 - *It has showed me that using failure as motivation can help future attempts rather than give up and hurt future attempts*
 - *It has made me think more about how to adapt after failure.*
 - *It has made me more interested in correcting mistakes*
- Growth mindset:
 - *It has helped be to think of failure better since every time I would not get the score I wanted I always was able to look at what I did wrong, learn from it, then always do better the next time even if it was by a little.*
 - *It has allowed me to realize failure is not the end of the world and I can use it to get better at certain things.*
 - *I need to take failures with a grain of salt and keep moving forward and focus on what I can do in the moment to improve.*
 - *This semester showed me that if I really want to learn something that I failed on before, I just need to work hard for it and get into a growth mindset.*
- Acceptance of failure and Increased resilience:
 - *This semester has definitely made me more resilient to failure in general, I feel that I will respond to failure in a much healthier way than I used to. I have a better understanding of how to also balance failures with successes, and that failures are to be expected and embraced.*
 - *I do not feel as bad when I fail because I realized that I might just need some more time than others to be successful but I CAN actually be successful if I continue to try.*
 - *It has totally revolutionized how I see failure if I am given a chance to reiterate it*
 - *I feel like I gained the ability to handle failure a bit better*

No Change:

- Already failure tolerant
 - *It hasn't changed my mindset very much, I had a pretty good outlook on failure before this class.*
 - *It hasn't a whole lot. A lot of my failing was freshman year, I really grew from that*
 - *Not really, I understand the importance of failure-based mindset thinking and receiving criticism in a constructive fashion.*
- No elaboration
 - *It hasn't really changed my mindset*
 - *I'm not sure that it has*
 - *I think I stayed the same throughout.*

Mixed Responses:

- *That failure is ok and you can learn from it BUT you still can only fail so many times so you need to still put in effort, if you fail too many times then it can become a negative thing very quickly*
- *I still found it hard to admit to my failure (especially to my classmates) even if they had experienced failure in the same way. However: I did like the grading method.*

Negative Change:

- *It has soured me on the idea because I feel that I am not going to receive the grade that I have earned in the class frankly.*