FAIL Is Not a Four-Letter Word: A Theoretical Framework for Exploring Undergraduate Students' Approaches to Academic Challenge and Responses to Failure in STEM Learning Environments

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ABSTRACT

Navigating scientific challenges, persevering through difficulties, and coping with failure are considered hallmarks of a successful scientist. However, relatively few studies investigate how undergraduate science, technology, engineering, and mathematics (STEM) students develop these skills and dispositions or how instructors can facilitate this development in undergraduate STEM learning contexts. This is a critical gap, because the unique cultures and practices found in STEM classrooms are likely to influence how students approach challenges and deal with failures, both during their STEM education and in the years that follow. To guide research aimed at understanding how STEM students develop a challenge-engaging disposition and the ability to adaptively cope with failure, we generate a model representing hypotheses of how students might approach challenges and respond to failures in undergraduate STEM learning contexts. We draw from theory and studies investigating mindset, goal orientations, attributions, fear of failure, and coping to inform our model. We offer this model as a tool for the community to test, revise, elaborate, or refute. Finally, we urge researchers and educators to consider the development, implementation, and rigorous testing of interventions aimed at helping students develop a persevering and challenge-engaging disposition within STEM contexts.

INTRODUCTION

Introduction of students to the "world of science" is usually marked by prototypical "cookbook" scientific demonstrations in which students follow step-by-step instructions that typically yield guaranteed results. While these experiences may help students learn tools and techniques in science, technology, engineering, and mathematics (STEM), they provide an incomplete experience of the process. Between these early academic experiences and Hollywood portrayals of instant scientific success, students are not made privy to the reality that struggles, ambiguity, and failure are inevitable hallmarks of the scientific process. In fact, navigating challenges, persevering through difficulties, and coping with failure are cited as some of the most important dispositions distinguishing outstanding scientists (Lopatto *et al.*, 2008; Laursen *et al.*, 2010; Harsh *et al.*, 2011; Thiry *et al.*, 2012; Andrews and Lemons, 2015; Simpson and Maltese, 2017). Yet, research on this issue, as well as instructor and student narratives, suggests that STEM students enter college ill-equipped to view failures and challenges as learning experiences (Marra *et al.*, 2012; Bennett, 2017; Simpson and Maltese, 2017), and this is rarely an explicit area of instruction or development emphasized in STEM classrooms (Traphagen, 2015; Simpson and Maltese, 2017). This gap between

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skills and instruction may leave students inadequately prepared to approach the challenges present in the broader landscape of scientific innovation and advancement, especially as today's scientific problems become increasingly complex and interdisciplinary (National Science Foundation, 2016; Friedman, 2017; National Academies of Science, Engineering, and Medicine, 2017; Simpson and Maltese, 2017). Advancing STEM will require not only a large, highly skilled workforce, but also one composed of challenge-engaging individuals who have the ability to persevere and cope productively with failure.

Therefore, we ask, "How and when do scientists develop dispositions that allow them to productively tackle challenges and learn from failure?" and "What can we, as researchers and educators, do to help build the next generation of perseverant, challenge-engaging scientists?" In this essay, we explore vetted psychological constructs and theories to build a model of how noncognitive factors may influence STEM undergraduates' engagement with challenges and ability to cope with failures in STEM learning contexts. We define "noncognitive factors" as "skills or dispositions not associated with development of knowledge or cognitive functioning," such as students' affective and motivational dispositions. Based on past research and theory, we describe five constructs that we believe affect STEM students' achievement both directly and indirectly through their responses to failure: mindset, goal orientation, fear of failure, attributions, and coping responses. Briefly, this essay addresses how mindset, or the beliefs a student holds about whether intelligence is malleable or fixed (Dweck, 2000, 2006), can influence a student's goal orientation, or their purpose when engaging in academic tasks (Pintrich, 2000a,b). Mindset and goal orientation are likely to influence a student's fear of failure, or concerns regarding the consequences of failure (Conroy *et al.*, 2001). These prefailure dispositions and beliefs affect postfailure attributions, what a student sees as the cause of a failure (Weiner, 1985), and the corresponding coping behaviors they employ in response to the threat of failure or an actual failure event (Skinner *et al.*, 2003).

Before we describe each factor in detail, it is important to define what we mean by "failures" and "challenges." In the broadest sense, a failure is the gap between an expected or desired result and what one ultimately experiences (Cannon and Edmondson, 2005). More specifically, we define "failure" as the inability to meet the demands of an achievement context, with the result of not achieving a specific goal. Achievement contexts 1) consist of some task(s) to be performed, 2) involve evaluating the performance of said task(s) against standards or expectations that indicate goal achievement, and 3) require certain competencies to carry out the task(s) to defined standards (Cacciotti, 2015). When an individual does not successfully carry out the task, they have *failed*. For example, not getting meaningful results from a scientific experiment when the expectation is that the results will have meaning constitutes a failure of that experiment, even if future experiments can be performed to rectify that failure. Importantly, our conceptualization of failure drawn from Cacciotti (2015) differs from that of some who argue that failure only occurs when one disengages and completely *stops* iterating or trying (e.g., Thomas, 2014). However, we also see failures as different from errors (e.g., Tulis *et al.*, 2016), in that failures are marked by not accomplishing a goal within an achievement context, while errors do not necessarily preclude accomplishment of a goal (i.e., errors can be corrected relatively quickly without failing). In this paper, "challenges" are achievement contexts that carry with them the risk of failure—that is, they push a student's skills and knowledge to a level at which the student risks a failure by engaging with them.

Even with these formalized definitions, what constitutes a challenge or a failure is influenced by one's personal goals, values, socialization, and so on. In other words, failure lies both in the eye of the beholder and in the expectations set forth by the context. So, while the typical grading scale and other standardized academic achievements certainly represent achievement contexts, individual students will also be influenced by other personal achievement contexts. A student who has been told that they must get all "A's" to achieve a future goal (e.g., medical school acceptance) may see receiving a "B" on an exam as failing. Alternatively, a student who regularly receives "C's" and "D's" and has the goal of passing the class may see a "B" as a success!

Students' views of failure interact with academic STEM contexts, manifesting in certain dispositions toward STEM challenges and behaviors in response to failure—in other words, students' mindsets, goal orientations, fear of failure, attributions, and coping responses. Herein, we synthesize research and theory on these five factors and aim to:

1. define each factor and discuss its underlying structures,
2. explain the likely influence of each factor on STEM undergraduates' approaches toward academic challenges and responses to failure,
3. present a model framework integrating all factors to explain how students might approach academic challenges and respond to failure within undergraduate STEM contexts, and
4. suggest next steps in discipline-based education research (DBER) and instruction to test this framework.

During this trajectory, we present four *minimodels* (Figures 1–4) that predict how each factor interacts with others to influence STEM students' abilities to navigate academic challenges. We also present theoretical and empirical support for these models in the Supplemental Material (Supplemental Figures 1–4). These minimodels build toward our larger model framework (aim 3; Figure 5). Thus, we aim to build understanding of each factor within the larger STEM challenge and failure context as we go. We have elected to present the constructs within our framework in a largely dichotomous way to help clarify connections between constructs. However, it is important to note that there is a great deal of complexity within any of the factors presented here (see *Considering Nuance*). It is our aim that this work will contribute to future DBER efforts to understand students' behaviors and outcomes in challenge and failure contexts and spark change in how we think about STEM curricular design and instruction to help students better navigate challenges and failures.

HOW STUDENTS APPROACH CHALLENGE

To start, we discuss the likely influence of STEM undergraduates' dispositions and goals on their engagement with a challenge *before* a failure occurs. We begin our discussion with the construct of mindset, which is likely to affect all subsequent factors either directly or indirectly.

Mindset

"Mindset," more formally known as "the implicit theory of intelligence," is a term introduced by researcher Carol Dweck in 1999. It gained worldwide fame in 2006 with the publication of her best seller *Mindset: The New Psychology of Success*. Through decades of research studying achievement and success, Dweck repeatedly noticed that individuals with similar skills and abilities experienced drastically different outcomes: some achieving great success, and others fading into obscurity. In some cases, individuals lacking basic skills and abilities rose to great heights through perseverance and hard work, while those with "raw talent" never reached their full potential. These patterns are visible across a wide variety of domains—in the classroom (Dweck, 2006, chap. 3, 2009), in the boardroom (McCall, 1998; Collins, 2001; Dweck, 2006, chap. 5), and on multiple sports fields (Wooden and Jamison, 1997; Lewis, 2005; Dweck, 2006, chap. 4). Dweck's ultimate conclusion is that success is less a result of one's abilities than of one's *beliefs* about one's abilities and the work put forth in improving those abilities.

At the heart of mindset theory is the idea that some individuals have a *fixed mindset*—they believe that intelligence and capacity for specific abilities are unchangeable traits—while others have a *growth mindset*—believing that these qualities are malleable and that the brain and our abilities can grow over time and through effort (Dweck, 2000, 2006). As an example of these dispositions in STEM contexts, we can look to our vignettes (Box 1). These vignettes represent fictional students constructed from the experiences of the authors and are meant to illustrate constructs. Names are pseudonyms. In the vignettes, we see that both Deirdre (vignette 1) and Nick (vignette 3) have fixed mindsets. Deirdre is "just not a numbers person," Nick "has always been a smart kid," and neither of them believes those facts to be changeable. In contrast, Riley (vignette 2) knows "they would have a lot to learn" but does not doubt that they will be able to improve their research skills over time, exemplifying a growth mindset. Notably, individuals can have a fixed mindset regarding some challenges and a growth mindset about others; one might have a fixed mindset about sports and a growth mindset about math, for example (Gross-Loh, 2015). Also, students can hold aspects of both a fixed and growth mindset at the same time (Dweck, 2006; Atwood, 2010; Claro *et al.*, 2016). Thus, mindsets depend on context, and one individual can hold fixed and growth mindsets about different things simultaneously.

The Impact of Mindset during Academic Challenge and Failure

One's mindset affects one in profound ways, influencing self-perception (e.g., Ehrlinger *et al.*, 2016), overall goals for learning (e.g., Haimovitz and Dweck, 2017; Lou and Noels, 2017), approaches to challenges and new opportunities (e.g., Dweck, 2007), and responses to criticisms and failures (e.g., Forsythe and Johnson, 2017). Individuals with a fixed mindset are more likely to see learning as an opportunity to prove their talent and intelligence, or "win," and may see academic challenges as things to be avoided (a *challenge-avoiding* disposition). They will likely quit easily in the face of challenges and become defensive under criticism, as they see it as a personal attack on fixed traits and personal worth (Forsythe and Johnson, 2017). For example, Deirdre (vignette 1) was unable to use her TA's constructive criticism to help her improve her math study skills. Instead, her

BOX 1. Vignettes demonstrating students' approach to challenges and response to failure

Vignette 1: Deirdre

Deirdre waited until she was a senior to take the required math course for her biology degree. When asked why, she would say it was because she is "just not a numbers person," so she knew the course would be challenging and wanted to avoid it as long as possible. After receiving a "D" on the first exam, Deirdre tells her friends that she's not surprised she did so poorly, because she was "so totally sick" on the day of the exam. Deirdre attends the first review session for the next exam, but after the TA (teaching assistant) calls on her to work through a problem and then points out a flaw in her logical reasoning and suggests some changes to her study methods, Deirdre decides that the TA just likes embarrassing students, so the sessions are "worthless." She does not attend any more sessions and thinks: "It is not my fault if I fail. The system is built to make me look dumb. It's not me that's a failure." After failing the second exam, she drops the class to avoid having an "F" on her transcript.

Vignette 2: Riley

Riley was excited to start working in their first laboratory position. They knew they would have a lot to learn, because they had never worked in a lab before, but they also knew that practical experience was the best way to gain the skills needed for their future career. As such, Riley was determined to truly understand each skill and become a proficient scientist. After gaining competence in basic laboratory skills, Riley is given their first lab project. For several weeks, Riley tries to get the first step in the process to work without success. They are disappointed, but try to think of the experience as an opportunity to learn, grow, and become a better scientist: "If I keep it up, I will get better. I know I have it in me." Riley knows that if they put in more effort, they will eventually succeed. They continue trying different solutions, incorporating feedback from the advisor, and even asking for additional help from lab mates. Eventually, Riley is successful and feels the thrill of having solved a challenging problem.

Vignette 3: Nick

Nick was the high school valedictorian. He has always enjoyed school, and academic success has always come fairly easily. He is very excited to be starting college, and he takes on a very ambitious course load for his first semester as a physics major, excited to prove his talent. But college courses are different than expected, and when midterms are over, Nick is shocked to find that he has "C's" in most of his courses. Nick schedules meetings with all his professors, and several of them suggest different ways that he might change his approach to note-taking and studying the course material. But Nick is confused by that. He has always been a smart kid, and smart kids do not have to study. If he must start studying now that he is in college, does that mean he is not actually smart? He starts to believe that he does not have the ability to grasp the material. The thought makes Nick anxious and upset, and whenever he sits down to study, he becomes distracted by negative thoughts. He spends hours in the library, but most of this "study time" is actually spent worrying and thinking "I have to do good on this next exam. I need to get an 'A.' I'll never become an astrophysicist if I don't get an 'A.' They're all naturally smart. If I can't get an 'A,' maybe I'm just not good enough. What will people think of me!?"

fixed mindset contributed to her conclusion that the TA was picking on her. Likewise, Nick (vignette 3) began to question his personal worth when his identity as a "smart kid" was threatened by his poor performance in physics, and his resulting anxiety led to rumination. In contrast, those having a growth mindset see learning as a chance to improve and actively seek out challenges, regardless of the risk of "looking silly" (a *challenge-engaging* disposition). They are more likely to be optimistic, to persevere in the face of setbacks, and to feel energized in the face of failures (Forsythe and Johnson, 2017). Under criticism, those with a growth mindset tend not to attach the feedback to their self-worth and focus instead on improving the target skill (Dweck, 2000, 2007; Ehrlinger *et al.*, 2016; Forsythe and Johnson, 2017). Accordingly, when Riley's (vignette 2) experiment did not succeed right away, they were able to use the advisor's feedback to work toward improving their research skills. The challenges they faced motivated them to continue putting forth effort, which ultimately led to success. Table 1 contains common phrases that students holding each of the two mindsets might think or say when approaching a challenge or confronting a failure.

While a fixed mindset is most often conceptualized as holding a fixed negative perception of one's abilities (e.g., vignette 1: Deirdre is "just not a numbers person"), individuals can hold fixed positive perceptions of their abilities as well (e.g., vignette 3: Nick "has always been a smart kid"). Individuals having fixed positive perceptions can succeed, at least for a while, with a fixed mindset. The problem is that this success, in large part, depends on their ability to avoid failure, often by avoiding challenges (Dweck, 2007). When such individuals do inevitably encounter struggle or failure, they often respond in an unproductive manner. So, when Nick was unable to avoid challenges and failures in his physics classes, he was ill-equipped to deal with these obstacles, which distracted him from productive action.

Although mindset studies in K–12 contexts are relatively common, there continues to be very little published research that specifically investigates mindset's effects on noncognitive factors in college-level STEM environments. Dweck (2006) did find that undergraduate students in introductory chemistry courses with growth mindsets demonstrated similar adaptive behaviors to those previously discussed (e.g., changing study strategies, seeing failures as opportunities for growth), while those with fixed mindsets used ineffective study methods, avoided challenges, and were more likely to lose interest in further pursuing chemistry. This suggests that mindset might have similar impacts in undergraduate STEM contexts as in previously studied contexts. Considering the potential of mindset interventions to shift how students approach challenges and respond to failures, it is worthwhile to further examine this construct in STEM-specific undergraduate contexts, as we propose in this essay.

Despite the strong focus on noncognitive factors as outcomes in this essay, it is worth noting that a majority of mindset studies have investigated academic success as an outcome of holding a growth mindset. Several studies, including correlational, quasi-experimental, and pre–post intervention designs, have found that a growth mindset is associated with higher academic achievement for students (e.g., Blackwell *et al.*, 2007; Paunesku *et al.*, 2015; Nichols, 2017). In contrast, fixed mindsets are often associated with low achievement (e.g., Dweck, 2000, 2007). However, in recent years, researchers have questioned the benefit of mindset interventions to improve academic success. Sisk and colleagues conducted two meta-analyses on this topic (Sisk *et al.*, 2018). In the first, they examined the link between mindset and academic achievement as well as possible moderators of that relationship. In the second, they looked at the relationship between mindset interventions and academic outcomes. After investigating the results of 129 studies in the first meta-analysis, Sisk and colleagues found only a weak relationship between mindset and academic achievement with very small effects. After analyzing the results of 29 studies for the second meta-analysis, they found very few significant relationships between interventions and academic outcomes. These results raise the question: "Does mindset actually improve academic success, and if so, for whom and in what contexts?" Notably, interventions that were found to be most successful improved performance for "at-risk" students (i.e., groups underserved in STEM) who were facing challenges (e.g., Aronson *et al.*, 2002; Yeager *et al.*, 2016). This nuance is acknowledged in the meta-analyses (Sisk *et al.*, 2018). Given that many studies did not find significant effects but that some studies did, researchers have called for additional studies to shed light on how mindset affects academic achievement in specific contexts (e.g., STEM contexts) and for specific groups, such as underserved groups in STEM (Sisk *et al.*, 2018).

While these meta-analyses bring into question the efficacy of mindset interventions to improve academic success specifically, they do not constitute an argument against our proposed framework. Sisk and colleagues (2018) did not consider noncognitive

TABLE 1. A comparison of fixed versus growth mindset using hypothetical student voices

	Fixed mindset	Growth mindset
Approaching a challenge	I'm not smart enough to do this. I'm not going to get anything out of this; so, I'm not going to put in my best effort. [Offers an excuse for any failures.] I shouldn't have to try this hard. Only dumb kids have to try in this class.	This will give me the chance to learn something new. I'm intimidated by this, so I'll break it down into smaller, more manageable projects and tackle them one-by-one to help me learn. This may not work, and that's okay. I can try my best and learn from my errors.
Confronted by failure	My first idea didn't work. This is "impossible." Why should I try? I'm not actually going to learn something from it. I am hopeless at this subject. This wasn't my fault. X ruined the experiment!	That didn't work. But I really want to solve this puzzle. I'll try it a new way. Every try will teach me something new, even if it doesn't work. If I keep trying, and incorporating what I learn, I'll make progress.

TABLE 2. A comparison of goal orientations using hypothetical student voices

	Approach	Avoid
Mastery	I want to understand why acids and bases are different.	I'm worried there are things about covalent bonding I don't completely understand.
Performance	I want to be in the 90th percentile on the MCAT.	I don't want to fail organic chemistry; I'll be so embarrassed.

factors that may result from mindset interventions (e.g., goal orientation, positive coping). We focus specifically on these factors in this essay, because they contribute to students' overall positive development (e.g., their ability to cope adaptively with failures and obstacles) and are arguably critical to success as students progress into their future careers.

Goal Orientation

A distinct construct, but one closely related to mindset, is goal orientation (Table 2), which describes the goals and aims students tend to hold when approaching a new task. These goals fall into two main orientations: 1) mastery or 2) performance (Pintrich, 2000a,b). Individuals with *mastery* goal orientations are motivated by a desire to *achieve* competence in a task. Riley (vignette 2) is an example of someone driven by mastery goals. Their aim in doing the work is to become a proficient scientist, and they seek to truly understand what they are doing. Alternatively, for those with a *performance* goal orientation, *appearing* competent to those around them is the central motivating factor. Nick (vignette 3) holds a clear performance goal orientation, placing high value on appearing smart to others. Another way of conceptualizing this is that mastery goals are internally driven by self-appointed standards, while performance goals are externally driven by normative standards (i.e., evaluation criteria agreed on by people of a certain group; Kassin *et al.*, 2017).

Further exploration shows that each type of goal orientation can be broken into two subtypes: approach and avoidance. Individuals with an *approach* orientation are driven by a desire to gain (or approach) success, much like Riley's (vignette 2) desire to *gain* competence. Those with an *avoidance* orientation, on the other hand, are driven to prevent (or avoid) failure, much like Deirdre's (vignette 1) desire to *avoid* failing her course or looking dumb. By crossing the two goal orientations with these subtypes, we arrive at four categories of motivations, represented in Table 2 (Elliot and Church, 1997; Elliot and McGregor, 2001). A student with a mastery-approach orientation is driven by a desire to succeed at some internally-held standard. By contrast, a student with a mastery-avoidance orientation seeks to avoid failing to meet an internally held standard. One with a performance-approach orientation wishes to attain success on some normative standard; someone with a performance-avoidance orientation wishes to avoid failing to meet a normative standard (Elliot and Church, 1997; Moller and Elliot, 2006; Chen *et al.*, 2009). Because of this 2×2 nature of goal orientations, we could assess two individuals as both having a mastery orientation. Yet, depending on whether their orientation is mastery-approach or mastery-avoidance, we would expect different approaches to challenge and responses to failure.

The Impact of Goal Orientation during Academic Challenge and Failure

Based on theory, we expect those who hold a performance orientation, regardless of whether it is approach or avoidance oriented, to exhibit the challenge-avoiding behaviors we previously discussed as being typical of a fixed mindset (seeking easy as opposed to challenging tasks, making excuses, etc.; Elliot and Dweck, 1988; Elliot and Church, 1997; Elliot and McGregor, 2001; Moller and Elliot, 2006). Empirical work supports this hypothesis. Individuals with performance orientations tend to show reduced effort, less creative thinking, and compromised problem-solving in challenging situations (Elliot and Dweck, 1988; Harackiewicz *et al.*, 2000; Doménech-Betoret and Gómez-Artiga, 2014; Mikail *et al.*, 2017). Furthermore, evidence from physics and chemistry graduates suggests that individuals with performance orientations tend to be less productive over the course of their career than individuals with mastery orientations (Hazari *et al.*, 2010). On the other hand, studies observe conflicting patterns of behavior among students with mastery orientations. Those with mastery-approach orientations consistently exhibit challenge-engaging behaviors (staying motivated, being optimistic, etc.; Elliot and Church, 1997; Elliot and McGregor, 2001; Chen *et al.*, 2009). The behavior of individuals with mastery-avoidance orientations is more ambiguous; they may exhibit either challenge-avoiding or challenge-approaching behaviors. Recall that mastery-avoidance students want to avoid failing to meet some internally held standard. This motivation may cause them to be extremely motivated to achieve, seeking out challenges to enhance their knowledge (challenge-approach). However, should they begin to experience obstacles and the specter of failure be raised, their behavior may change. They may begin to offer excuses or reduce effort, cushioning their self-worth by offering other reasons, beside personal ability, for why they may not succeed (challenge-avoiding; Chen *et al.*, 2009).

While certain behaviors might often indicate the presence of a specific goal orientation, this is not always the case, and we must consider this interaction with more nuance. For example, if Deirdre (vignette 1) and Nick (vignette 3) were both in your class, you might notice that neither of them completed an optional study guide for an upcoming exam. While their actions were the same, their behaviors were motivated by different goal orientations. Deirdre likely assumed that the study guide, like the TA in the study session, would be "worthless," because she perceives that the "system" is designed for her to fail. This would allow her to justify her failure and avoid attributing the failure to her own shortcomings, thus avoiding embarrassment or shame (performance-avoidance). Nick, however, was probably so distracted by his negative thoughts and his need to perform at the highest level that he could not focus enough to complete the study guide (performance-approach). Although outwardly these two students appear similar, they are in fact motivated by different factors, and their internal processes are different. Similarly, two students with high grades might be motivated by two very different underlying goal orientations; one may have a mastery-approach orientation, while the other may have a performance-approach orientation. Although both

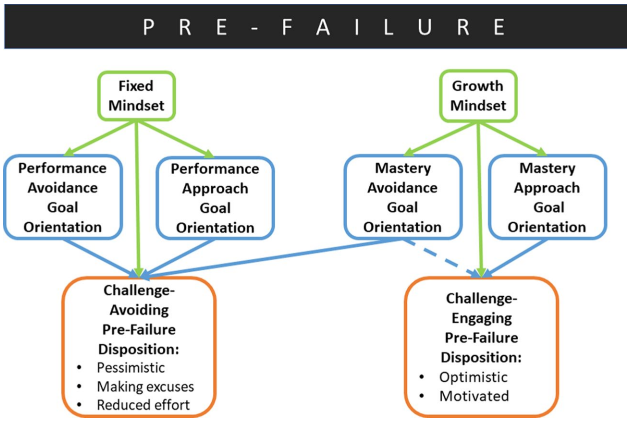

FIGURE 1. Minimodel 1: mindset and goal orientations. Predicted relationships between mindset (green), goal orientation (blue), and prefailure disposition (orange) for undergraduate STEM contexts. Solid lines represent relationships with empirical support in the literature, primarily drawn from contexts outside undergraduate STEM learning (Supplemental Figure 1). Dashed lines represent relationships without empirical support. Growth mindset leads to a challenge-engaging prefailure disposition; fixed mindset, by contrast, leads to a challenge-avoiding prefailure disposition. Growth mindset leads to mastery goal orientations, while fixed mindset leads to performance goal orientations. Performance goals lead to a challenge-avoiding disposition. Mastery-approach goals lead to a challenge-engaging disposition and mastery-avoidance goals tend to lead to challenge-avoiding dispositions. We predict, however, that some individuals with mastery-avoidance goals may express challenge-engaging disposition (dashed line).

students may typically be high achievers, they respond quite differently when a challenge results in failure, especially because students with mastery-approach orientations are buffered against the negative impact of failure on self-worth (Niiya *et al.*, 2004). This is something we should consider as instructors when helping students navigate challenges and failures. To help visualize the interconnectedness between these themes in the literature of mindset, goal orientations, and prefailure dispositions for STEM undergraduates, we created minimodel 1 (Figure 1).

Fear of Failure

Yet another noncognitive factor at play within this paradigm is fear of failure (FF), which has a strong influence on how students might approach an academic challenge. FF has been explained by aspects that are emotional/affective (i.e., a temporary negative emotional state; Martin and Marsh, 2003), related to personality (i.e., a stable trait oriented toward avoiding situations in which failure is likely; Noguera *et al.*, 2013), and cognitive (i.e., perceptions of achievement contexts as threats to success; Conroy, 2001). Modern studies recognize that all three components contribute to one complete definition of FF (Cacciotti, 2015; Conroy *et al.*, 2001). Namely, FF is a "temporary cognitive and emotional reaction towards environmental stimuli that are apprehended as threats in achievement contexts" (Cacciotti, 2015, p. 39). It is also important to acknowledge that the effect of any one factor on FF depends on the particular achievement context an individual is facing (Conroy *et al.*, 2001).

The Impact of FF during Academic Challenge and Failure

In general, FF has a negative influence on challenge engagement (e.g., Bledsoe and Baskin, 2014). Perhaps the most negative outcome of FF is that it leads to *self-handicapping*, the creation or assertion of obstacles that might "explain away" poor performance on a task (Elliot and Church, 2003; Elliot and Thrash, 2004; Bartels and Herman, 2011). Self-handicapping commonly involves 1) making excuses either before or after failure occurs and 2) reducing effort (Berglas and Jones, 1978; Chen *et al.*, 2009; del Mar Ferradás *et al.*, 2016). As an example, Deirdre (vignette 1) engaged in both of these behaviors. She excused her poor performance by asserting she was "totally sick," and she reduced effort by not attending study sessions. Now, after future failures, Deirdre can console herself: "Well, of course I didn't do that well; I didn't even go to the study sessions!" Self-handicapping is a defense mechanism that protects one's sense of self-worth in the short term by alleviating threats, but it has high long-term costs (Zuckerman and Tsai, 2005; Chen *et al.*, 2009; Cox, 2009). In Deirdre's case, not going to the study sessions and excusing her poor performance might protect her from immediate failure or feeling "stupid," but it ultimately had negative effects on her class performance. This result is typical of such behavior (Zuckerman and Tsai, 2005; Chen *et al.*, 2009). Collectively, the two forms of self-handicapping may be thought of as contributing to a challenge-avoiding prefailure disposition.

As we have already discussed, individuals are likely to enter challenges with different goal orientations. These goal orientations interact with FF to predict which prefailure disposition an individual is likely to exhibit (Figure 2). Because individuals with a mastery-approach orientation are driven by a desire to achieve internal standards, they are less likely to view challenges as threats (Elliot and Church, 1997; Chen *et al.*, 2009). FF is therefore unlikely to influence, or be influenced by, the mastery-approach orientation. FF is, however, related to the other three goal orientations (Moller and Elliot, 2006). Those with avoidance orientations (both performance and mastery) wish to prevent some real or perceived incompetence, making them more likely to interpret challenges as threatening and leading to higher FF (Elliot and Church, 1997; Elliot and Thrash, 2004). People with avoidance orientations are thus likely to increase self-handicapping behaviors, resulting in an overall challenge-avoiding disposition (Elliot and McGregor, 2001; Conroy and Elliot, 2004; Chen *et al.*, 2009). Fear of failure is also related to performance-approach orientations, as some individuals seek achievement as a way to avoid failure (Elliot and Church, 1997; Conroy and Elliot, 2004). Notably, individuals with a performance-approach orientation who are *also* high in FF actually show fewer challenge-avoiding behaviors such as self-handicapping (Elliot and Church, 1997; Elliot and McGregor, 2001; Chen *et al.*, 2009). This relationship is likely attributable to these individuals making an effort to achieve to avoid realizing their FF. The concern, then, is how these individuals will respond when struggles and failures become unavoidable, as is often the case in science, where pursuit of novel discoveries requires engagement with situations in which failure is likely.

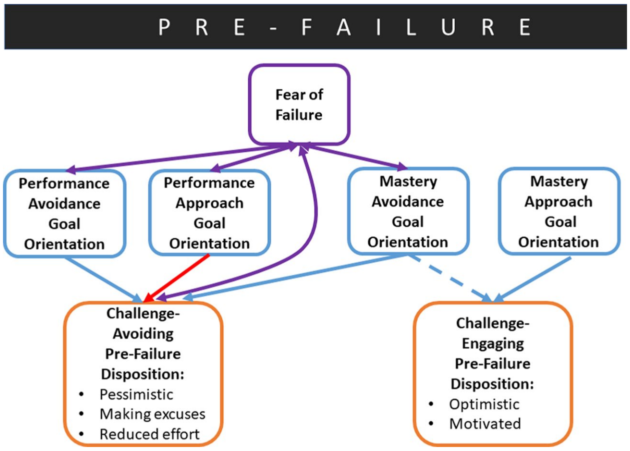

FIGURE 2. Minimodel 2: FF and goal orientations. Predicted relationships between fear of failure (purple), goal orientation (blue), and prefailure disposition (orange) for undergraduate STEM contexts. Solid lines represent relationships with empirical support in the literature primarily drawn from contexts outside undergraduate STEM learning (Supplemental Figure 2). Dashed lines represent relationships without empirical support. Reciprocal relationships exist between FF and challenge-avoiding prefailure dispositions and also between FF and three of the four goal orientations: mastery-avoidance, performance-approach, and performance-avoidance. Goal orientations may directly influence the different prefailure dispositions. Note that performance-approach goal orientations are hypothesized to be related to *lower levels* of challenge-avoiding behaviors like making excuses and reduced efforts when combined with higher FF (red line), which is different from the predictions in minimodel 1 in the absence of FF.

Altogether, the current state of the literature suggests that the interaction of goal orientations and FF in predicting behavior is highly complex.

An understanding of the causes of FF is key to analyzing why we see such variable individual behavior. Conroy and colleagues (2001) interviewed elite performers and athletes in depth about 1) how they determine whether or not something is a failure and 2) their perceived consequences of failing. Based on respondents' answers, those authors assert that FF comes from the influence of five distinct factors: 1) fear of shame or embarrassment (e.g., "When I am not succeeding, I worry about what others think of me."); 2) fear of devaluing one's self-estimate (e.g., "When I am failing, I blame my lack of talent."); 3) fear of having an uncertain future (e.g., "When I am failing, it upsets my 'plan' for the future."); 4) fear of losing social influence (e.g., "When I am not succeeding, some people are not interested in me anymore."); and 5) fear of upsetting important others (e.g., "When I am failing, I lose the trust of people who are important to me."). An understanding of which fears are most related to specific goal orientations and, thus, to prechallenge dispositions, could help explain the differences seen in actual rates of self-handicapping behaviors and different prefailure dispositions in STEM. However, there is very little research addressing these questions in undergraduate STEM contexts. More nuanced investigations will be of great importance, because students with high FF might be less likely to pursue STEM degrees or, if they do choose STEM fields, could experience high levels of attrition when confronted with challenges (Cacciotti, 2015). As a starting point for these investigations, we use the research described here to build minimodel 2, which explores FF, goal orientations, and prefailure dispositions (Figure 2).

HOW STUDENTS RESPOND TO FAILURE

Thus far, we have described constructs that primarily influence how STEM students engage with challenges (i.e., antecedents to failure), which in turn affect subsequent responses to failure. In this section, we focus on factors that describe the way students perceive failures and respond after they occur. We explore the relationships between these factors and the constructs discussed earlier.

Attributions

Attributions are the perceived causes of successes or failures that occur in an achievement context (Weiner, 1985). Researchers describe attributions using three qualities. "Locus" refers to whether we see the cause as initiating from within ourselves (e.g., "I was responsible") or outside ourselves (e.g., "They were responsible"; Rotter, 1966; Weiner, 1985). "Stability" refers to whether a cause is relatively permanent (i.e., whether the cause is lasting and unchangeable from context to context) or impermanent (Rotter, 1966). "Controllability" refers to whether or not we view a cause as within our control (Weiner, 1979). Different combinations of these three characteristics result in four commonly perceived causes of success and failure: ability, effort, task difficulty, and luck (Weiner *et al.*, 1971). An ability attribution assigns cause to one's ability or inability to do a task. Ability was originally described by Weiner as having an internal locus that is stable and uncontrollable (1985). Effort, on the other hand, assigns cause to the effort one exerts during the task and is considered internal, unstable (i.e., the amount of effort one exerts can change from situation to situation), and controllable. Task difficulty and luck have an external locus, meaning that students view the cause of the failure as initiating from a source outside themselves. Task difficulty is considered external, stable, and uncontrollable, while luck is considered external, unstable, and uncontrollable. Other examples of each of these attributions as they might be used by students after experiencing a classroom challenge can be viewed in Table 3.

Whether or not an attribution is viewed as stable and controllable determines whether a student will view past failures and future challenges as within their control and respond with productive strategies intended to avoid future failures. Whether an attribution is viewed as internal or external determines how the failure will affect a student's self-esteem and self-efficacy following the outcome (Weiner *et al.*, 1971; Clifford *et al.*, 1988; Sukariyah and Assaad, 2015; Simpson and Maltese, 2017). These characteristics have important implications for how students cope with failures and are also related to the various constructs discussed earlier.

The Impact of Attributions during Academic Challenge and Failure

STEM students' prefailure dispositions are likely to predict postfailure attributions. These, in turn, are likely to predict how students ultimately cope with failure. Students with a fixed

TABLE 3. An illustration of different failure attributions using student voices

Ability: Internal, stable, uncontrollable	Effort: Internal, unstable, controllable
I just couldn't understand the formulas on the exam. I'll never pass this class.	I didn't try as hard on this lab report as I probably should have. I'll have to work harder next time.
Task difficulty: External, stable, uncontrollable	**Luck: External, unstable, uncontrollable**
These test questions are impossible! No wonder I failed the exam.	I just got unlucky on some of those multiple-choice questions. Fingers crossed that my results come out good next time!

mindset are likely to use ability attributions or external attributions to explain failures (Dweck and Leggett, 1988; Mueller and Dweck, 1998; Robins and Pals, 2002). These students see ability as stable and uncontrollable, which often leads them to adopt a helpless response pattern in which they view future failures as inevitable (Dweck and Leggett, 1988; Elliot and Dweck, 1988; Robins and Pals, 2002). Thus, they disengage or become preoccupied with fears about failure. This is exemplified by Nick (vignette 3), who views his lack of ability as the obstacle to his success. This is counter to a student with a growth mindset who is likely to view failure as related to a lack of effort (Dweck and Leggett, 1988; Hong *et al.*, 1999; Robins and Pals, 2002; Blackwell *et al.*, 2007; Baird and Harlow, 2012; Smiley *et al.*, 2016). Like Riley (vignette 2), such a student is likely to view a failure as something that was within their control (internal locus and controllable), could have been changed, and can be changed in the future (unstable). Growth-minded students are therefore much more likely to use adaptive coping strategies and to tolerate failure to a greater degree (Clifford *et al.*, 1988; Hong *et al.*, 1999; Smiley *et al.*, 2016).

Similar to mindset, goal orientations show strong relationships with effort and ability attributions. In general, mastery goals predict effort attributions, whereas performance goals predict ability attributions (Ames and Archer, 1988; Robins and Pals, 2002; Grant and Dweck, 2003; Smiley *et al.*, 2016), although certain contexts (e.g., group vs. individual work settings) and student backgrounds (e.g., hailing from an Asian culture) may change this relationship (Grant and Dweck, 2003). Some work suggests that goal orientations completely mediate the effect of mindset on attributions; that is, mindset only affects attributions via its influence on goal orientations. For example, Smiley *et al.* (2016) proposed that mindset affects whether one holds mastery or performance orientation goals and that these goals, *not mindset*, influence postfailure attributions. But more research is needed to investigate whether this is always the case.

While most work has focused on how mindset and goal orientations influence ability and effort, which are internal attributions, it is worth considering predictions regarding external attributions for failure, including luck and task difficulty. As discussed earlier, FF and avoidance goal orientations lead to self-handicapping behaviors, which result in external attributions for failure (Chen *et al.*, 2009; del Mar Ferradás *et al.*, 2016). This is reflected in vignette 1, when Deirdre blames her failure on being sick and even sets herself up to blame her future failures on the TA before these failures have even occurred. Having external attributions protects against the negative effects that failing may have on one's self-efficacy (Weiner *et al.*, 1971; Zuckerman, 1979; del Mar Ferradás *et al.*, 2016). At times, this may help scientists to maintain their motivation, and indeed, some professional scientists hold external attributions for failure (e.g., Simpson and Maltese, 2017). Yet such external attributions are often seen as uncontrollable, which leads to pessimistic views about future success (Núñez *et al.*, 2005) and thus maladaptive coping (discussed below).

An interesting exception to this is found in work done with typical college-age (20- to 24-year-old) Navy recruits. This work examined a factor considered external, unstable, and controllable—the strategy one uses to achieve a particular task. Recruits who attributed failure to this cause tended to have as positive or more positive responses to failure than students who attributed the failure to effort (Clifford *et al.*, 1988). This may be because this attribution is seen as both *controllable* and *external*, which might alleviate self-blame associated with failure while also resulting in adaptive coping. This result aligns with much research supporting the claim that attributions viewed as unstable and controllable are likely to elicit adaptive coping responses from students, because they allow students to view failures as temporary and within their control. Therefore, we have incorporated these characteristics into minimodel 3 (Figure 3). Because theory and research on external versus internal loci affecting coping are mixed and indicate both negative and positive responses to failure, we have not included these in our model.

Coping

We define "coping" as individuals' behavioral responses to stressors (such as failures) that typically serve to allow one to tolerate or minimize the stress (Skinner *et al.*, 2003). Identifying the specific coping mechanisms STEM students use when dealing with academic challenges and subsequent failures and relating them to the constructs previously discussed can help us better understand how and why our students respond in certain ways, as well as how these responses influence their success and long-term well-being. For example, a student may cope with stress by engaging in problem solving with the intention of figuring out and alleviating the problem causing the stress, as Riley (vignette 2) did when they continued to troubleshoot their research project. Alternatively, they may choose to escape the stress by avoiding the stressful situation or disengaging mentally, as demonstrated when Deirdre (vignette 1) did not attend study sessions and dropped her class (Skinner *et al.*, 2003). A coping mechanism can be considered *adaptive* when it helps an individual maintain their well-being and/or move beyond a stressor or *maladaptive* when it exacerbates threats to the individual's well-being and prevents resolution or progress beyond the stressor (Carver *et al.*, 1989; Lazarus, 1993; Skinner *et al.*, 2003; Shin *et al.*, 2014). Whether or not a coping mechanism is considered adaptive or maladaptive depends on the specific stressor (Lazarus, 1993; Skinner *et al.*, 2003). For example, it may be maladaptive to avoid a stressor when it can be easily resolved with little effort (e.g., a student may avoid failing an

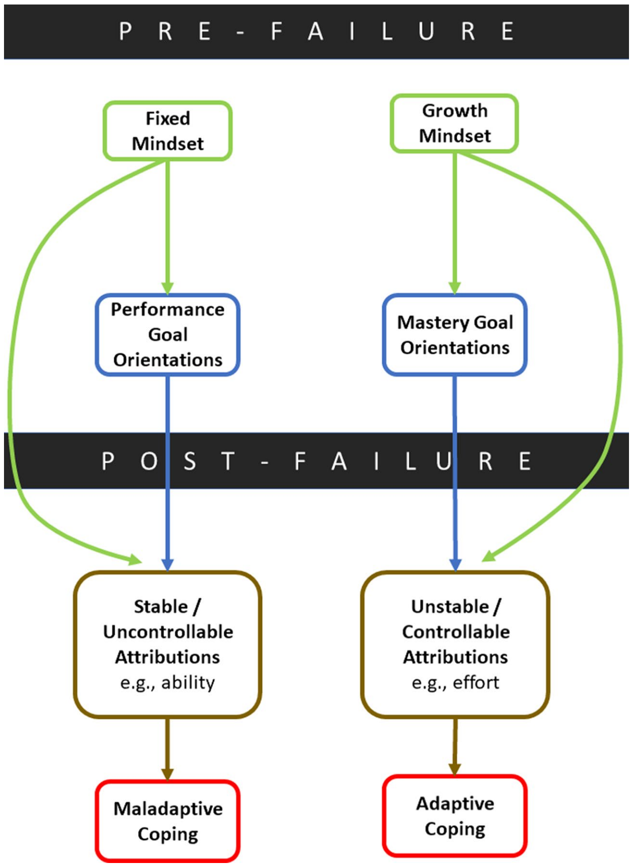

FIGURE 3. Minimodel 3: attribution. Predicted relationships between mindset (green), goal orientation (blue), attributions (brown), and coping style (red) for undergraduate STEM contexts. Solid lines represent relationships with empirical support in the literature primarily drawn from contexts outside of undergraduate STEM learning (Supplemental Figure 3). Those with a growth mindset and mastery orientations are more likely to attribute the cause of a failure to something within their ability to change. This, in turn, is related to more adaptive coping behaviors. By contrast, those with fixed mindsets and performance goal orientations are likely to judge failures as resulting from something beyond their control, which is related to maladaptive coping.

exam simply by studying), but it could be adaptive to avoid a stressor when nothing can be done to resolve it. For example, when a student realizes that they cannot do well in a course due to unforeseen personal challenges, the student may choose to avoid course challenges by dropping the course. Thus, to assess whether a coping strategy is adaptive or maladaptive, we must consider context.

Coping can be considered either a stable characteristic of an individual or context dependent, with an individual's coping strategy depending on the stressor and context at hand (reviewed in Lazarus, 1993). We view coping as largely context dependent; that is, the context interacts with the person to determine the kind of coping strategy they will employ. This view aligns with our ideas that coping can be unique to the academic context a student experiences, and the characteristics of that context, such as class supports and instructor actions, influence coping. However, we also draw upon theory that predicts that coping responses to similar situations will become increasingly stable over time (Spencer *et al.*, 1997). Thus, we expect students to have predispositions toward certain coping styles—perhaps resulting from their mindsets, goal orientations, and past coping experiences—but to be influenced by the context in which they experience a stressor. In keeping with the view of coping as context specific, we define "adaptive academic coping" as coping that both helps students to maintain well-being and moves them productively toward desired academic outcomes and "maladaptive academic coping" as coping that poses a threat to students' well-being and/or prevents students from achieving desired academic outcomes.

Postfailure Coping and Relationships with Other Constructs

In their extensive review and critique of coping structure, Skinner and colleagues (2003) describe multiple distinct categories of coping that are well-supported in the broader coping literature (Table 4). Evidence in the literature suggests that several of these categories are likely to be consistently adaptive or maladaptive in K–12 academic contexts (Struthers *et al.*, 2000; Brdar *et al.*, 2006; Alimoglu *et al.*, 2010; Sevinç and Gizir, 2014; Shin *et al.*, 2014). We draw on this work to predict whether these strategies might serve as adaptive or maladaptive in undergraduate STEM contexts and present these predictions along with example quotes in Table 4. Although we anticipate exceptions to our predictions, these generalizations will likely hold in undergraduate STEM contexts based on previous work.

As previously discussed, the specific strategies that students use to cope with a problem or stressor matter, because they can either advance students through problems and support their well-being (adaptive) or they can prevent problems from being solved and exacerbate threats to well-being (maladaptive). Furthermore, coping strategies become increasingly stable over time (Lazarus, 1993; Spencer *et al.*, 1997), leading to trends in how students deal with problems in specific contexts. So, STEM students who avoid studying for chemistry once are more likely to avoid studying again later in the semester and in future classes. Similarly, students who blame others for a first research failure may also be more likely to do so as their research careers progress. Practicing maladaptive coping strategies can have lasting consequences. However, as STEM instructors, we have the opportunity to leverage the constructs described earlier to help students adopt and practice adaptive coping strategies and to create a climate in which adaptive coping is a more likely response to failure (see *Implications for Research and Instruction*). This can have lasting positive consequences for our students.

We use the research described earlier to build minimodel 4 (Figure 4), which explores our predicted relationships between prefailure dispositions, adaptive and maladaptive coping, and long-term outcomes for STEM undergraduates.

PUTTING IT ALL TOGETHER: PREDICTING HOW STEM UNDERGRADUATES APPROACH CHALLENGES AND RESPOND TO FAILURE

Just as prefailure disposition can be predicted based on mindset, goal orientation, and FF, so can students' postfailure attributions and coping styles. We know from research outside STEM

TABLE 4. Definitions (adapted from Skinner *et al.*, 2003), examples of coping behaviors in academic contexts using hypothetical student voices, and predicted outcomes of specific coping constructs

Coping construct	Definition	Example	Predicted outcome
Problem solving	Attempting to solve the stressor at hand, such as planning a potential solution and enacting that solution.	I messed up the first time, but I think I figured it out by troubleshooting and repeating the experiment. (Also see vignette 2.)	Adaptive
Support seeking	Use of available social resources for help with the stressor or to receive emotional comfort.	Dude, I am so bummed that I messed this up! Can you help me figure out what went wrong? (Also see vignette 2.)	Adaptive
Information seeking	Attempting to learn more about a stressful situation or condition in order to understand the cause, consequences, or potential solutions to a problem.	I am going to go to office hours to discuss why I failed my O-Chem exam. Even if I can't change my grade, at least I'll understand what I did wrong.	Adaptive
Cognitive restructuring	Attempting to change one's view of a stressor in order to see it in a more positive light.	I didn't get clear results on that experiment, but that is okay because I sure learned a lot. (See vignette 2.)	Adaptive
Emotional regulation	Attempting to influence one's own emotional distress (to alleviate or mollify emotional distress) and to constructively express emotions at the appropriate time and place.	I failed my biology exam, but that is okay, I just need to take a deep breath, because I know I can do better on the next one. I have to just keep calm.	Adaptive
Accommodation	Accepting the stressor and no longer trying to directly act to solve the stressor. Does not preclude acting to circumvent or navigate the stressor.	I didn't get clear data on my experiment. But that is okay, because sometimes these things just happen in science.	Either
Negotiation	Proposing a compromise or making a deal with others to alleviate or solve the stressor.	I'll make you a deal Professor, if I completely redo my lab, will you at least give me half credit?	Either
Distraction	Engaging in an alternative pleasurable activity in an attempt to alleviate emotional distress associated with a stressor.	I'm so stressed, I can't concentrate on studying right now. I am going to play some video games and come back to it when I can focus.	Either
Escape	Avoidance of the problematic environment and/or stressor, including denial of the stressor.	I think I am going to drop this chem major, it is just too tough. (Also see vignette 1.)	Maladaptive
Social withdrawal	Avoiding other people or preventing other people from knowing about a stressor or its effects.	I am just not going to tell my parents about my grades. They don't need to know I failed. It's not their business anyway.	Maladaptive
Rumination	Repeatedly thinking negatively about a stressor and about one's own role in that transaction. Associated with catastrophizing and self-blame.	I don't know what I will do now that I have failed intro biology. There is no way I will be a doctor. I am so stupid. What will I do now? (Also see vignette 3.)	Maladaptive
Helplessness	Acting to give up or relinquish control of a situation.	I am so tired from all my STEM classes and studying that there is no way I can do well.	Maladaptive
Delegation	Shifting the problem to someone else through maladaptive help-seeking such as whining and self-pity.	I am so bad at math. You are so good at it. Can you do these for me? There is no way I'll get them right.	Maladaptive
Opposition	Externalizing one's negative emotions as behaviors directed at others in connection with the stressor.	It is my stupid group's fault that I didn't do well in the class. They're horrible. They didn't do one bit of the work on our final project!	Maladaptive

and in K–12 settings that students who hold a growth mindset, are low in FF, and/or approach problems with mastery goal orientations (challenge-approach) tend to attribute failures to controllable, unstable causes (effort attributions) and respond with adaptive problem-focused coping strategies that advance their ability to learn from the problem and make progress (Clifford *et al.*, 1988; Heine *et al.*, 2001; Brdar *et al.*, 2006; Mortenson, 2006; Shin *et al.*, 2014; Snyder *et al.*, 2014; Smiley *et al.*, 2016; Lou and Noels, 2017). Likewise, students who hold a fixed mindset, are high in FF, and/or have a performance-based or avoidance-based goal orientation (challenge-avoidance) tend to attribute failures to uncontrollable causes (ability attributions) and cope by venting, avoiding the problem, and distancing themselves mentally from the perceived failure (Heine *et al.*, 2001; Robins and Pals, 2002; Brdar *et al.*, 2006; Mortenson, 2006; Shin *et al.*, 2014; Snyder *et al.*, 2014;

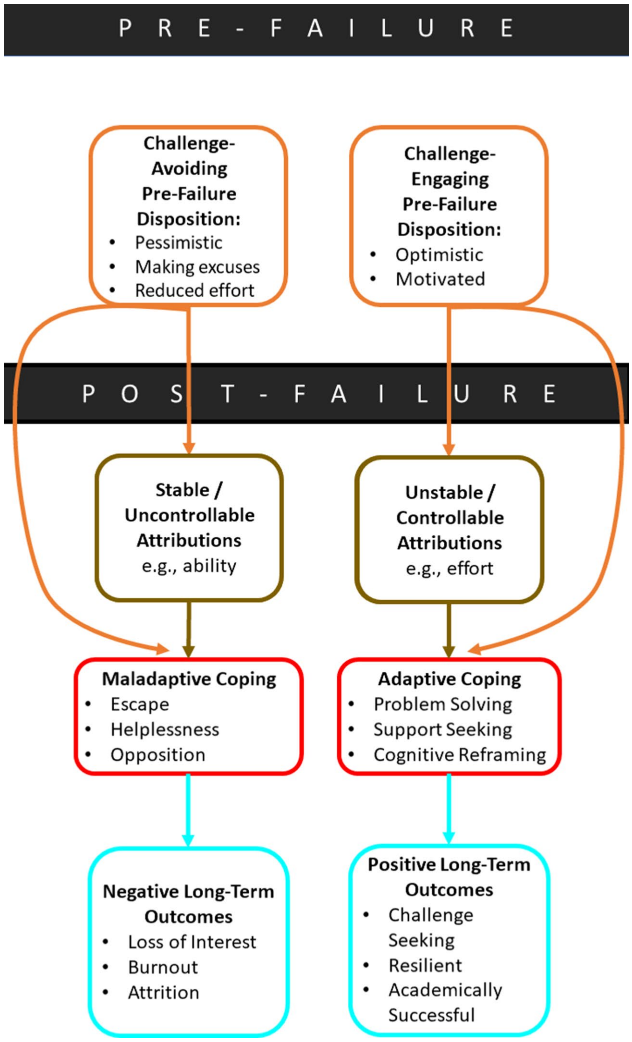

FIGURE 4. **Minimodel 4 - Prefailure dispositions, Coping, and Long Term Outcomes: Predicted relationships between prefailure dispositions (orange), attributions (brown), coping responses (red), and long term outcomes (turquoise) for undergraduate STEM contexts. Solid lines represent relationships with empirical support in the literature primarily drawn from contexts outside undergraduate STEM learning (Supplemental Figure 3). Individuals with challenge-engaging dispositions are likely to attribute failure to unstable and controllable causes and engage in adaptive coping. These students are likely to experience academic success. Individuals with challenge-avoiding dispositions are likely to attribute failure to stable and uncontrollable causes and engage in maladaptive coping. This likely leads to loss of interest in the STEM discipline, burnout, and often attrition.**

Smiley *et al.*, 2016; Lou and Noels, 2017). Holding with our definition of "maladaptive," these coping strategies do not further these students' learning and result in further threats to their well-being.

Based on these findings, we predict that STEM undergraduates who use adaptive coping strategies will tend to demonstrate a greater ability to navigate scientific obstacles, seek out subsequent challenges, and show perseverance and a positive disposition in the face of setbacks. We can also predict that STEM undergraduates who use maladaptive coping to deal with challenges are more likely to lose interest in pursuing STEM education, to suffer burnout, and to leave STEM. In an effort to bring theory to bear on our understanding of how STEM undergraduates develop the ability to navigate failure, and as a starting point for future investigations, we present an integrated complete model predicting how the previously discussed concepts influence STEM undergraduates' engagement with academic challenges and responses to failures (Figure 5). This model integrates the four previously presented minimodels. In this final model, the lines present *predicted* relationships, because, as of yet, little empirical support exists for these relationships in STEM undergraduate contexts. However, each relationship is based on empirical evidence present in work from K–12 contexts or higher-education outside STEM (see Supplemental Figures 1–4). It is our hope that this comprehensive model will generate future directions for DBER research and rich discussion aimed at uncovering how undergraduate STEM students develop into perseverant, challenge-engaging individuals. However, we caution our readers that this model is an imperfect representation of reality as described in the following sections.

Considering Nuance

In the previous sections, Figure 5, and much of the literature addressing these concepts, each concept is distilled to its most defining characteristics, and typical examples are presented in order to construct a clear picture of interactions between constructs. Yet, in reality, these constructs and their interactions are much more complex. Three primary considerations increase this complexity.

First, though these constructs are often presented as dichotomous or discrete, with individuals falling into mutually exclusive units, they in fact represent continuous spectra and are often *not* mutually exclusive. For example, students may believe that intelligence is malleable *to a point* but that there is a certain amount of our intelligence that is fixed. These students would fall in the middle of the spectrum from growth to fixed mindset, termed "mixed mindset." In fact, Dweck's research has found that around 20% of the general population have mixed mindsets (Dweck, 2006). There are also specific examples of this in K–12 academics and athletics (Atwood, 2010; Claro *et al.*, 2016). Students can also hold multiple goal orientations at once. In fact, many studies describe how students hold a mastery-approach goal orientation at the same time as a performance-approach goal orientation (e.g., Pintrich, 2000a). Likewise, after a single failure, a student may hold both uncontrollable and controllable attributions (Weiner, 1985). This can make it challenging to tease apart the effects of these dispositions. It can make it even more challenging to consider how to apply knowledge of these constructs in a STEM classroom, as it can be hard to easily discern students' dispositions.

Second, whether or not a student adopts a growth mindset, mastery orientation, or controllable attribution is highly context dependent. For example, we know that one's mindset can vary depending on the discipline or achievement context (Atwood, 2010; Claro *et al.*, 2016), and we hypothesize that mindset may also vary among subdisciplines. This has led to studies that highlight how students can hold different mindsets depending on the academic setting (Quihuis *et al.*, 2002) and

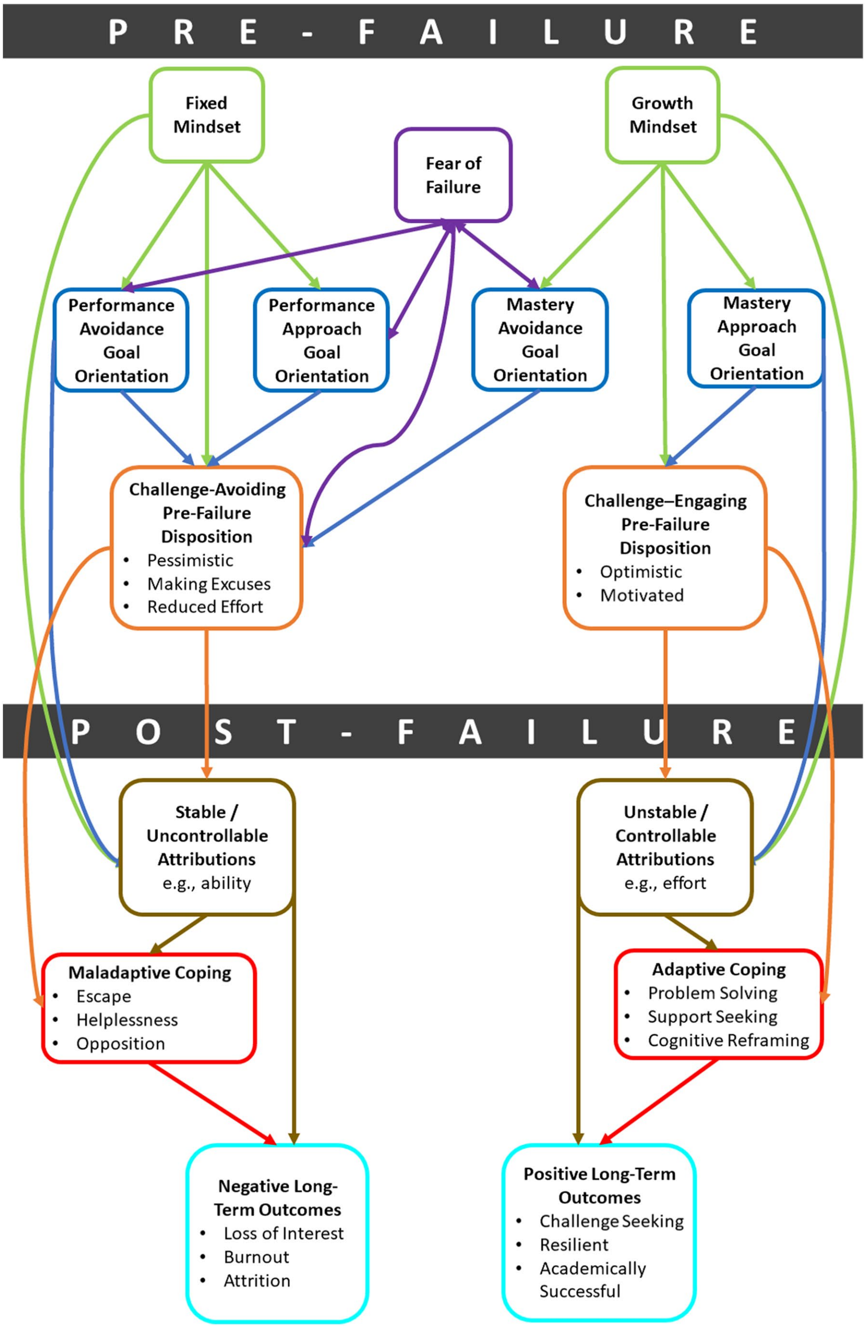

FIGURE 5. The failure mindset coping model. All connections from previous minimodels are modeled simultaneously, leading to the emergence of two pathways. On the right, growth mindset and mastery goal orientations are linked to more positive long-term outcomes through a challenge-engaging disposition, controllable attributions, and adaptive coping. On the left, a fixed mindset and performance goal orientations are related to more negative long-term outcomes via interaction with fear of failure, challenge avoidance, uncontrollable attributions, and maladaptive coping. All relationships (solid arrows) represent predicted relationships between constructs in undergraduate STEM contexts. However, all relationships are supported by previous work outside undergraduate STEM contexts (see Supplemental Figures).

the development of instruments to measure mindset in specific academic domains (e.g., I'lhan and Çetin, 2013). Coping responses to failure also vary across disciplines. For example, professionals in math fields were less likely to see embracing failure as a part of their success than those in other STEM disciplines (Simpson and Maltese, 2017). In addition, aspects of the learning context apart from discipline affect these constructs. Grant and Dweck (2003) found that group work was more likely to push students toward a performance goal orientation regardless of their mindset and regardless of whether they attributed their success or failure to effort. They hypothesized that, in a group context, students would be more responsible for the outcomes of the group and thus feel more pressure to perform. This example illustrates that how we structure the learning environment is likely to influence students' dispositions and also that it can alter expected relationships between constructs. Thus, while the model presented above draws on the *most typical* relationships between these constructs, these relationships do not always hold.

Third, a student's background and culture influence these constructs and the degree to which students might respond to interventions targeting each construct. This is important because these differences exist along lines that distinguish historically underserved students from well-served students in STEM. For example, mindset interventions have had a more beneficial effect for disadvantaged students (Blackwell *et al.*, 2007; Yeager *et al.*, 2016; Fink *et al.*, 2018), leading to increased academic achievement and retention in college courses (Aronson *et al.*, 2002). Emphasizing a growth mindset has been shown to buffer the negative effects of poverty (Claro *et al.*, 2016) and stereotype threat among racial minorities (Good *et al.*, 2003). Mindset interventions have also been shown to be effective in reducing the achievement gap between men and women (Good *et al.*, 2003). In addition, holding a mastery-approach goal orientation has a more positive effect on members of underrepresented groups. Due to phenomena including stereotype threat and low belonging, minority groups in majority settings (women, racial/ethnic minorities, low socioeconomic status, etc.) are likely to perform better when they emphasize their individual ability to master the material instead of their performance in front of others (Darnon *et al.*, 2018). Differences across international lines also play a role, as Korean students who have performance goal orientations often attribute failure to lack of effort (Grant and Dweck, 2003), a relationship that would be uncommon in American culture, which typically associates mastery goal orientations with effort attributions. Responses postfailure are no exception, with gender and culture playing a role in choice of coping strategy. For example, Simpson and Maltese (2017) describe how women are more likely than men to personalize failure, while men use it as a motivator. Additionally, in a study comparing coping responses to academic failure in Chinese versus American university students, American students were more likely to engage in support seeking than their Chinese counterparts (Mortenson *et al.*, 2009).

We advocate for considering and exploring this nuance in both future research and instruction within undergraduate STEM contexts. Importantly, a more nuanced approach will allow us to consider how each student's unique characteristics and life experiences influence the interplay of these factors and will allow us to examine instances in which the models above do not apply, which may prove more informative than typical cases.

Implications for Research and Instruction

Across DBER disciplines, there are relatively few studies that examine STEM undergraduates' dispositions before failure and their reactions postfailure. There are even fewer that consider interactions between three or more of the concepts discussed here. This is an important area of work in which DBER scholars can make a contribution. The model presented in this paper, which draws on theory and research from a variety of fields, is one framework that could guide such investigations. However, there are many other theories and frameworks that could also be used to address these questions (see *Limitations, Assumptions and Related Constructs for Consideration*), and we hope to encourage broad exploration of this topic. Given the complexity of the proposed model, it is unlikely that any one study would appropriately and fully test all hypothesized relationships among variables. Rather, we suggest that mixed-methods studies that investigate the potential correlational and causal links among several, but not all, of the variables described in our model would be the most effective means of providing support for this framework. Further convergent evidence could also then be built through the use of meta-analysis and systematic reviews. An accumulation of evidence over time can support, or refute, aspects of the model, much like studies of other complex models described in social psychology (e.g., Lent *et al.*, 2002). More specifically, we feel that this model could help frame studies that aim to 1) examine how prefailure dispositions and responses to failures are unique in the undergraduate STEM learning context—a context in which failures are common and yet students often enter with an expectation of fast success; 2) distinguish between how student-level factors (e.g., preclass dispositions and attitudes as addressed in this essay) and course-level factors (e.g., instructor actions and class design not addressed in this essay) affect how students approach challenges and respond to failure; and 3) design and examine interventions aimed at helping students engage with challenges and respond to failures. This third priority, which is strongly supported by the other two, should be a central focus of future DBER work, considering the widespread goals of student retention in STEM fields and development of the next generation of challenge-engaging, perseverant scientists.

Work on interventions is at the heart of both future research and instruction because interventions are instructor implemented and can be tested and adjusted via DBER research. Each construct in our model is a leverage point at which to employ and test interventions. Fortunately, work done mainly in K–12 contexts can inform intervention design. Prior interventions on mindset have exposed students to this concept through in-person or online explanations of how intelligence can change with effort (e.g., Hong *et al.*, 1999; Blackwell *et al.*, 2007; Yeager *et al.*, 2016). In general, mindset interventions resulted in more productive problem solving, increased resilience, and use of productive coping strategies (Hong *et al.*, 1999; Blackwell *et al.*, 2007), and they have been successfully employed in STEM university settings (e.g., Fink *et al.*, 2018). Although questions remain regarding whether these interventions are effective in increasing academic achievement (Sisk *et al.*, 2018), we hypothesize that they promote other important outcomes for STEM students, such as willingness to confront research challenges and improved ability to cope with failure. Interventions targeting goal orientations have long focused on promoting a collaborative or individualistic, instead of competitive, learning culture in order to help students develop a mastery goal orientation (Ames, 1984; Johnson *et al.*, 1985; Ames and Archer, 1988; Roseth *et al.*, 2008). FF interventions have mainly targeted affective components of this construct, such as anxiety before exams, aiming to reduce the negative emotions associated with fear of failure before a challenge (e.g., Neff *et al.*, 2005; Hjeltnes *et al.*, 2015). Finally, attribution retraining, in which instructors use explicit language attributing failures or successes to controllable causes have proved successful in university and STEM K–12 contexts in shifting students attributions (e.g., Chodkiewicz and Boyle, 2014). These are only limited examples of what could be done, and much more work exists that addresses interventions targeting these constructs and can be leveraged by undergraduate STEM instructors.

Despite the obvious value of prior intervention development and research, it is important that instructors and researchers implement and test these interventions in STEM undergraduate environments. Individuals undergo many biological, cognitive, social, and personality changes during the transition to college and early adult periods (Steinberg, 2014), which may affect their responses to interventions. In addition, many of the factors are context dependent (see *Considering Nuance*). Thus, investigating the efficacy of interventions across STEM will be important. To guide this work, we can draw on research with mindset interventions that has yielded recommendations for best practices likely to be useful for creating interventions on *all* noncognitive factors included within our model (Walton, 2014). To be most effective, interventions should aim to:

- persuade, not compel, students to adopt a change;
- recognize the importance of students' subjective experiences;
- target recursive processes (Fink *et al.*, 2018); and
- not be intended as a "magic bullet" or "one size fits all" fix (Yeager and Walton, 2011).

Ideally, teams of psychologists, education researchers, and instructors can draw upon these best practices to design and test impactful interventions within our proposed framework.

Finally, beyond employing and testing interventions, it is important that undergraduate STEM instructors also consider the questions and constructs presented here when designing curricula and especially when students are likely to encounter significant challenge or failure. Curricular design, pedagogical style, and instructor dispositions are likely to have large effects on how students approach academic challenges, make errors, and respond when they fail. For example, instructors may need to allow adequate time to address challenges, work through failures, or iterate to help students develop their ability to navigate failure and achieve other valued outcomes (Corwin *et al.*, 2018; Gin *et al.*, 2018). Likewise, a classroom's overall "error climate" influences how students react to errors that may occur during challenges (Steuer *et al.*, 2013). Instructors may also want to consider how evidence-based instructional approaches, such as incorporating random call or group work into classes might influence engagement with challenges and response to failure or moderate these through effects on students' affect or behavior (Grant and Dweck, 2003; England *et al.*, 2017; Cooper *et al.*, 2018). STEM instructors and course designers can draw upon new research in DBER and theory from psychology and K–12 education to inform classroom practice, with the aim of creating environments that assist students in developing persevering, challenge-engaging dispositions. Together with research in STEM education and DBER fields, these actions will bring us all one step closer to facilitating the growth of a next generation of scientists who are capable (and excited) to take on this century's scientific challenges in innovative ways.

Limitations, Assumptions, and Related Constructs for Consideration

While the previous discussions are starting points from which to consider how broadly explored psychosocial constructs influence how students approach challenges and respond to failures, this is far from a comprehensive exploration of the literature. We must recognize the constraints and assumptions of the model we present. This model 1) includes only student-level noncognitive dispositions, and excludes contextual factors, pedagogical factors, and demographic factors; 2) makes the assumption that success is a desired outcome by students, although this may not always be the case; 3) is limited to an examination of instances in which failure is a possible outcome; 4) draws connections based mainly on quasi-experimental and correlational work (very few of the studies we draw upon are experimental and include randomization; cause cannot be inferred with complete certainty). In addition, other constructs merit mention and recognition due to their potential to influence these processes. Yet these constructs are not included, because they fall outside of scope of our model.

An extensive body of work headed by Manu Kapur (e.g., Kapur, 2010, 2014a,b, 2016) describes how instructors can design classroom activities for "productive failure" by creating challenging tasks that students are unlikely to successfully complete (Kapur and Bielaczyc, 2012). The idea behind productive failure is that students who work on such challenges will, by necessity, consider more of the critical features of a concept in their attempt to complete a task that is just beyond their skill level than they would completing a task at which they would be likely to succeed. This increases their engagement and attention to critical features in subsequent instruction, increasing learning (Kapur and Bielaczyc, 2012). This work is concerned primarily with how the instructors' deliberate curricular design choices impact student learning of concepts. Alternatively, our model focuses primarily on students' psychosocial dispositions as they relate to any failure context, planned or not. Thus, this work is beyond the scope of this paper. However, scholars considering students' psychosocial dispositions during an approach to challenge or response to failure may find this work useful because Kapur and colleagues also consider how students' psychosocial dispositions may influence their engagement with planned failure activities.

Work on learning from errors (Tulis *et al.*, 2016) likewise may be useful in consideration of how students approach challenges. Errors are described as an unintended discrepancy between a current and desired state or deviation from a given standard by Maria Tulis, the pre-eminent scholar in this field (Tulis *et al.*, 2016, 2018). Notably, they are distinguished from failures, because they do not necessarily preclude accomplishment of a goal; they are at a finer grain size. While our model focuses on the larger grain size of failures that do preclude goal achievement, constructs drawn from the literature on learning from errors may be of use. For example, students' beliefs about errors as learning opportunities are likely to influence their reaction to errors made while tackling challenges and may ultimately influence success or failure (Tulis *et al.*, 2018). Also, as for many of the constructs discussed earlier, students holding a mastery goal orientation are more likely to believe that they can learn from errors than students who hold a performance goal orientation (Tulis *et al.*, 2018). In addition the error climate in a classroom can influence how students address errors and their motivation during a challenge (Steuer *et al.*, 2013), indicating that this may be a target for classroom interventions. Thus, while the focus of this work is at a finer grain than what we addressed earlier, it is an important body of literature meriting consideration.

Our model assumes that academic achievement is a desired goal, but this assumption is not always true. Fear of success is a construct that can be employed to understand how students approach challenge and respond to failure (or success) when success is *not* the desired goal. Originally characterized to explain underperformance of otherwise capable men (Freud, 1957; Ogilvie, 1968) and women in the workplace (Horner, 1968), fear of success describes a fear that success in an achievement setting will result in a some type of individual loss, negative impact on social standing, and/or undue burden to maintain high standards (Ogilvie, 1968; Metzler and Conroy, 2004). Fear of success is a construct related to FF, in that both describe a type of anxiety experienced in achievement contexts, but because fear of success is not attributed to the anticipation or experience of a failure event, it is outside the scope of this discussion.

A large and heavily influential area that we chose not to address in this work is emotions that moderate approach to challenges and responses to failure. The literature on students' emotional response to failure is extensive and complex. Indeed, there is work on how excitement, enjoyment, pride, shame, anxiety, boredom, anger, and frustration, among others, relate to challenges and failures and how these mediate or moderate coping responses or influence engagement in STEM (e.g., Tulis and Ainley, 2011; Smiley *et al.*, 2016; England *et al.*, 2017).

However, we chose to focus this article primarily on cognitive and motivational aspects that influence this process. The one exception to this is FF, which has both cognitive and affective components and which we decided to include in our model. A large and longer review would be useful to elaborate on what we know about the role of affect and emotion in this process.

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