Journal of Pre-College Engineering Education Research (J-PEER)

Volume 7 | Issue 1 Article 4

2017

Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering

Pamela S. Lottero-Perdue
Towson University, plottero@towson.edu

Elizabeth A. Parry
North Carolina State University, elizabeth.parry.consulting@gmail.com

Recommended Citation

Lottero-Perdue, P. S., & Parry, E. A. (2017). Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering. *Journal of Pre-College Engineering Education Research (J-PEER), 7*(1), Article 4.
https://doi.org/10.7771/2157-9288.1158

Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering

Abstract

This mixed methods study examines perspectives on failure in the classroom by elementary teachers new to teaching engineering. The study participants included 254 teachers in third, fourth, and fifth grade who responded to survey questions about failure, as well as a subset of 38 of those teachers who participated in interviews about failure. The study first examines the literature about failure in the contexts of engineering and education. Failure is positioned as largely normative and expected in engineering, whereas in education, learning and failure have a more tenuous relationship. Identity, failure avoidance, failure as part of the learning process, growth and fixed mindset, resilience, perseverance, and grit are addressed in a discussion of failure and education. Quantitative and qualitative research methods were utilized to examine how participants: reacted to the words failure or fail, reported allowing students to fail or revise their work, considered how failure should be avoided in education, considered how failure may be construed as a learning experience, and reported using the words failure or fail in their classrooms. Conclusions from the study include that: failure has a largely negative connotation within education and by teachers, which influences how teachers use the words fail and failure and create failure experiences for their students; many teachers practice resilience and perseverance and encourage similar practices in their students with respect to mistakes in the classroom, which serves as a helpful yet somewhat inaccurate analogue for failure in engineering design; and there is evidence that many teachers have adopted a growth mindset and encourage this mindset in their classrooms – however, there are some challenges to a true adoption of this mindset by teachers.

Keywords

failure, design process, elementary

Document Type

Invited Contributions: Best Papers from ASEE Pre-College Engineering Education

Cover Page Footnote

This paper is part of a set of papers recognized by the American Society for Engineering Education's Pre-College Engineering Education Division as one of the division's best papers from the 2015 and 2016 conferences. This is the first set of ASEE Pre-College Engineering Education Division best papers J-PEER has republished, with permission from the American Society of Engineering Education.

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 7:1 (2017) 47–67

Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering

Pamela S. Lottero-Perdue[1] and Elizabeth A. Parry[2]

[1]*Towson University*
[2]*North Carolina State University*

Abstract

This mixed methods study examines perspectives on failure in the classroom by elementary teachers new to teaching engineering. The study participants included 254 teachers in third, fourth, and fifth grade who responded to survey questions about failure, as well as a subset of 38 of those teachers who participated in interviews about failure. The study first examines the literature about failure in the contexts of engineering and education. Failure is positioned as largely normative and expected in engineering, whereas in education, learning and failure have a more tenuous relationship. Identity, failure avoidance, failure as part of the learning process, growth and fixed mindset, resilience, perseverance, and grit are addressed in a discussion of failure and education. Quantitative and qualitative research methods were utilized to examine how participants: reacted to the words failure or fail, reported allowing students to fail or revise their work, considered how failure should be avoided in education, considered how failure may be construed as a learning experience, and reported using the words failure or fail in their classrooms. Conclusions from the study include that: failure has a largely negative connotation within education and by teachers, which influences how teachers use the words fail and failure and create failure experiences for their students; many teachers practice resilience and perseverance and encourage similar practices in their students with respect to mistakes in the classroom, which serves as a helpful yet somewhat inaccurate analogue for failure in engineering design; and there is evidence that many teachers have adopted a growth mindset and encourage this mindset in their classrooms – however, there are some challenges to a true adoption of this mindset by teachers.

Keywords: Failure, design process, elementary

Teaching engineering in elementary school represents more than the addition of a relatively new subject to the elementary curriculum (National Research Council [NRC], 2012; Next Generation Science Standards [NGSS] Lead States, 2013). It also represents an intersection of two cultures: that of engineering and that of elementary school. These cultures are communities of practice, each having distinct interests, identities, resources, tools, and ways of using language (Lave & Wenger, 1991). Engineers are the primary participants in the former of these communities, and children and teachers in the latter. Elementary engineering education represents the formation of a new community of practice in which elementary students, guided by their teachers, learn to engineer (Figure 1).

Ideally, teachers in this new community facilitate children's engagement in engineering practices, engineering habits of mind, and engineering design processes (Cunningham & Carlsen, 2014a; Cunningham & Lachapelle, 2014; National Academy of Engineering [NAE] and NRC, 2009). They also help students navigate failure experiences, which, as we describe below, are inherent within engineering. The development of this community requires that there be more opportunities for pre-service and in-service teachers to learn to teach engineering (NAE & NRC, 2009, 2014). It also

http://dx.doi.org/10.7771/2157-9288.1158

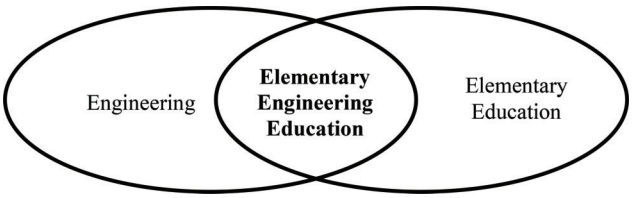

Figure 1. Engineering, elementary education, and elementary engineering education communities of practice.

demands that engineering educators who provide those learning opportunities gain a richer understanding of: the elementary education context in which teachers work, and how knowledge that teachers construct within this context may support or challenge teachers as they learn to teach engineering.

Our study attends to this demand to better understand the perspectives that teachers bring with them as they enter into the elementary engineering community. Specifically, we investigate how these teachers perceive of failure experiences and fail words (e.g., fail, failure, failing). We begin with background about how failure is regarded within the culture of engineering, and then summarize how failure has been regarded within the culture of education.

Background

Failure in Engineering

Although the broad goal of engineering is to generate successful solutions to problems, the opposite of success—failure—guides and informs engineering design. Henry Petroski, who has written extensively about engineering failure, offered:

> Because every successful design is the anticipation and obviation of failure, every new failure—no matter how seemingly benign—presents a further means towards a fuller understanding of how to achieve a fuller success. (2012, p. 45)

There are multiple ways in which engineers respond to and consider failure as they attempt to solve problems. In this section, which is by no means an exhaustive account of failure in engineering design, we elucidate how engineers: (1) learn from failed designs within the engineering design process (EDP) (including testing to failure); (2) learn from failed final designs; and (3) design for failure.[1]

The first of two of these ways that engineers engage with failure—learning from and testing to failure—represent the broad idea that engineers use failure as an essential feedback mechanism. The iterative nature of the EDP presumes that the first (or second, third, etc.) design is unlikely to represent the best solution to the problem (Cunningham & Carlsen, 2014b). In other words, early designs are likely to fail to acceptably meet the criteria established at the beginning of the design process. For example, a wind turbine prototype may be considered a failure if it does not produce a minimum desired power output. Also, depending on the context of the design problem or solution, engineers may test designs to a point of failure. Concrete formulations, for example, are tested to failure by exerting increased static compression load onto solid concrete cylinders until they break.

Learning from failure during the design process is productive. However, the final solution that emerges from the EDP—for example, offered to a client or constructed for public use—is indeed intended *not* to fail. Petroski asserted: "No one, especially an engineer, wants a system or device to fail to perform its design correctly and completely" (2012, pp. 45–46). However, final products indeed do fail for a variety of reasons including mistakes or omissions during the design process and unforeseen uses or conditions of use (Cajas, 2001).

One way that a final engineered product may fail is that it does not acceptably meet the clients' or the public's criteria for product success. The design of the antennae within the iPhone 4, for example, resulted in dropped calls and customer dissatisfaction. A final designed solution may also be considered a failure when other products simply perform better. Consequences of these kinds of failure to respond to the market and compete within it include lost revenue, a stain on a company's reputation, and an opportunity to reconsider design criteria for a next-generation product.

As history has demonstrated time and again, the products of engineering may also fail catastrophically, resulting in loss of engineering licensure, property damage, serious injury, and/or death. Engineers learn from such end-point failures, as well, analyzing the cause of these disasters and applying this new learning to future designs. An example no doubt studied by countless engineering students was the Hyatt Regency Skywalk collapse in 1981, which killed 114 people and injured over 200 and was traced to an engineering design change in the tie rods that were intended to hold the skywalk (Delatte, 2009).

Finally, engineers also design for failure, anticipating under what conditions failure is likely to occur, and subsequently taking that into consideration as they design. Engineers over-design, using factors of safety (e.g., a part may be designed to be three times stronger than required) or redundant parts within systems (e.g., multiple engines on a jet plane, so that if one engine fails, the plane can still fly) to prevent malfunction, catastrophic injury, or loss of life. Also, a component within a system may be purposefully sacrificed (e.g., a fuse) to protect other elements of the system. Further, engineers may design the way in which a component fails—a strategy called "managed failure" (Petroski, 2012, p. 49). An example of this is the use of

[1] In this paper, for simplicity we use "the EDP." However, we recognize that there are multiple EDPs used by engineers and educators.

laminated safety glass in automotive front windshields so as to allow the glass to both give and be contained upon impact.

In summary, failure is a normative condition in engineering. Designs are tested to failure or said to fail when criteria are not met. Failure is to be anticipated, analyzed when it occurs, and prevented or managed; in this sense, failures are not mistakes. At the end state of the EDP, failure is negative. Engineers do not want a final product, be it a bridge, an artificial knee joint, or a new computer operating system, to fail. It may be a stretch to say that engineers celebrate failure—rather, engineers welcome feedback that will ultimately help them make better design decisions. Quite often, that feedback comes wrapped in the context of a failed attempt.

Failure in Education

Just as there are multiple perspectives on failure within the engineering profession, there are different contexts and meanings for failure within education. We explore five of these here: (1) failing performance, (2) identifying as a failure, (3) avoiding failure, (4) learning from failure, and (5) providing failure experiences in education. Within the first three ways of thinking about failure in education is the perspective that failure should be avoided; however, in the fourth and fifth emerges a different way of thinking in that failure can and should be embraced as a learning opportunity. In the course of exploring these failure themes in education, we describe two mindsets from the work of Carol Dweck, which provide insight into why students (and others) may tend towards avoiding or embracing failure (Dweck, 2008). Further, we discuss the concepts of resilience and grit as they pertain to failure.

Students failing tests, assignments, and courses are clearly events that students and their teachers, parents, and guardians would like to avoid. Many grading systems skip the letter E altogether, moving directly from D to F, emphasizing the point that *F*ailure has occurred (i.e., criteria for a passing grade have not been met). Further, and catalyzed by *No Child Left Behind,* multiple books and articles have examined "failing schools" and "failing teachers" and have considered what to do about them in an era of public accountability (e.g., Favero & Rutherford, 2016; Murphy & Meyers, 2008; Nicolaidou & Ainscow, 2005). Beyond the notion of failing schools, modest performance of students in the United States on international assessments such as PISA (the Program for International Student Achievement) suggest to some that perhaps the entire school system is failing our students (Berliner, 2011). Be it the "failing" teacher, school, or system, the key suggestion here is that students are not receiving the full benefits that education ideally has to offer.

Education, however, is not simply about performance. As students learn, they form their identities. "Learning," offered Brickhouse, "is a matter of deciding what kind of person you are and want to be" (2001, p. 286). In other words, learning and identity are bound. Students may identify as "failures" within school in general or within particular aspects of school—unhealthy identifications that most educators, parents, and guardians do not wish for students to assume. Dweck, in her book, *Mindset*, differentiates failure as identity, "I am a failure" with failure as action, "I failed" (2008, p. 33). She argued that those who tend to identify as failures (i.e., to think "I am a failure") have a "fixed mindset."

A fixed mindset in the context of education may be defined as: "A belief system that suggests that a person has a predetermined amount of intelligence, skills or talents" (Ricci, 2013, p. 3). Such a mindset doesn't necessarily lead to self-identification as a failure, yet "can lead students to interpret academic challenges as a sign that they may lack intelligence—that they may be 'dumb' or might be seen as 'dumb'" (Yeager & Dweck, 2012, p. 302). Individuals with this fixed mindset are likely to think in the following way:

> You were smart or you weren't, and failure meant you weren't. It was that simple. If you could arrange successes and avoid failures (at all costs), you could stay smart. Struggles, mistakes, perseverance were just not part of the equation. (Dweck, 2008, p. 4)

Note the theme of avoidance of failure in this fixed mindset.

Dweck juxtaposed the fixed mindset—where challenges and failures were to be avoided—with a growth mindset. Ricci described growth mindset as "a belief system that suggests that one's intelligence [or skills or talents] can be grown or developed with persistence, effort, and focus on learning" (2013, p. 3). Dweck reflected on such growth mindset individuals as follows:

> They knew that human qualities, such as intellectual skills, could be cultivated through effort. And that's what they were doing—getting smarter. Not only weren't they discouraged by failure, they didn't even think they were failing. They thought they were learning. (2008, p. 4).

The focus for these individuals was on learning and improving as they were challenged and even as they failed.[2] Dweck clarified in a commentary that the effort employed when enacting a growth mindset was not simply effort using the same approach (which failed), but rather involved trying again in new and different ways, seeking assistance, etc. (2015). Further, she asserted that we do not simply have a fixed or a growth mindset, in general, but

[2] There is debate about how malleable we are in terms of intelligence, talent, or character. That, however, is not the point for Dweck. Rather, her point is that a growth mindset—a belief that we are malleable—is a productive, resilient, positive way of interacting with the world.

rather, "we're all a mixture of fixed and growth mindsets" (2015, p. 3).

Research has suggested that students who have, are exposed to, or develop a growth mindset may experience a variety of positive outcomes. For example, middle school students with a growth mindset increased their overall school performance over a period of two years, whereas fixed mindset students neither increased nor decreased their performance (Blackwell, Trzesniewski, & Dweck, 2007). In the same study, seventh graders who learned about the malleable nature of intelligence in an intervention study had higher motivation than a control group. In another study, female university college students enrolled in a mathematics course who received the growth mindset message that mathematical ability is acquired had a higher sense of belonging and intent to study mathematics in the future than those who received the message that mathematical ability is fixed (Good, Rattan, & Dweck, 2012). Other studies demonstrate the benefits of a growth mindset on lessening adolescent students' aggression and stress (Yeager & Dweck, 2012), and on the reduction of the impacts of stereotype threat on adolescents' test scores (Good, Aronson, & Inzlicht, 2003). An example of such a stereotype threat is a female student's concern that she might confirm the stereotype that as a female, she will perform less well on mathematics tests.

Those with a growth mindset are resilient, responding positively and productively in the face of challenge and failure. Resilient responses are "positive and beneficial for development" and include "seeking new strategies, putting forth greater effort, or solving conflicts peacefully" (Yeager & Dweck, 2012, p. 303). A related concept and resilient response within the growth mindset is perseverance, i.e., continuing to do something despite the challenge it presents. Persevering over a long period of time with sustained interest is what Duckworth and colleagues have coined "grit" (Duckworth, Peterson, Matthews, & Kelly, 2007). In contrast to resilient responses such as perseverance, non-resilient responses are "negative or not beneficial for development" and include "helplessness, giving up, cheating or aggressive retaliation" (Yeager & Dweck, 2012, p. 303).

In a *New York Times* article "What if the Secret to Success is Failure?" (2011) and later in his book, *How Children Succeed: Grit, Curiosity and the Hidden Power of Character* (2012) journalist Paul Tough interviewed a variety of students, educators, and other educational stakeholders about how we can help students avoid big failures in life. These included: staying or becoming poor, dropping out of school, or living a life of violence, and being identify by self or others as "a failure." Themes from Tough's investigative journalism include that:

- students and teachers should develop and employ a growth-minded approach with respect to both intelligence and character (citing Dweck's work);
- schools must help students develop perseverance, grit, and self-control (citing Duckworth and colleagues' work); and
- education that safeguards students from failure experiences is neither growth-minded, nor will not enable the development of perseverance, grit, and self-control.

In other words, Tough argued that it is necessary to intentionally teach students how to fail, persevere and respond with resilience. Other educators have made similar arguments. Drawing from Dweck's work directly, Mary Cay Ricci's *Mindsets in the Classroom* (2013) and Debbie Silver's *Fall Down 7 Times, Get up 8* (2012) both advocate that teachers: (1) create a classroom climate that values the learning that comes from failure experiences, (2) explicitly model growth-minded, resilient responses to failure for their students; and (3) provide opportunities for students to practice how to positively and productively respond to failure.

Failure and Growth Mindset in Elementary Engineering Education

Elementary engineering education aims to engage children in engineering in ways that are both authentic to engineering practice and developmentally appropriate. Analyzing catastrophic failures may be too disturbing and designing for failure may be too complex at the elementary level. However, children's analysis of failed designs within the EDP is a fundamental aspect of this iterative process that is appropriate and achievable at the elementary level. Engagement in the EDP involves students creating and testing a first design, which is evaluated based upon test results and the extent to which criteria have been met and constraints have been followed. Subsequent designs aim to improve upon the performance of the first or other previous designs, and are similarly objectively evaluated. Elementary children may also test their designs to failure to gather feedback during the EDP. Evaluation of failed designs and test-to-failure experimentation helps students promote a growth mindset where failure is simply feedback, taken objectively to inform next steps.

The *Framework for K–12 Science Education* has included failure analysis for elementary students within K–12 engineering practices and core ideas (NGSS Lead States, 2013; NRC, 2012). Failure analysis is a key component of the following performance expectation within the Next Generation Science Standards:

> Performance Indicator 3-5 ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. (NGSS Lead States, 2013)

Further, advocates of project-based instruction, problem-based learning, and case-based reasoning for elementary

and middle school students have asserted the importance of failure analysis as a part of design education (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Cunningham, 2009;Kolodner et al., 2003).

Whereas failure analysis can be quite complex in the engineering profession, failure analysis in elementary-level design challenges is usually straightforward— "the cause of failure is often quickly apparent and can be addressed" (Cunningham & Carlsen, 2014b).[3] Such analysis may purposefully involve a reconsideration and reinforcement of scientific concepts (Cajas, 2001; Kolodner et al., 2003; Fortus, Dershimer, Krakcik, Marx, & Mamlok-Naaman, 2004; Hmelo, Holton, & Kolodner, 2000; Levy, 2013). For example, analysis of failure of a bridge collapse may enhance students' developing understanding of force, stability, and gravity (Cajas, 2001), and the design of an artificial lung or model of a lung requires that students consider the function of a lung and how it operates within the respiratory system (Hmelo et al., 2000).

There are multiple examples in the literature of elementary children testing their designs to failure. For example, in a packaging unit within the City Technology curriculum, children: "… fill paper and plastic bags with containers of water until they fail … determine the nature and location of the failures and … develop proposals for improving the performance of the bags" (City Technology Project, 2013; NRC, 2012). Another example of elementary students testing to and learning from failure is the wrecking ball test of strength of a rock-and-mortar wall within the materials engineering unit in the Engineering is Elementary curriculum (EiE, 2011).

In order to fully engage in the EDP, students must—at least temporarily—adopt a growth mindset. Recall that a growth mindset is an approach that assumes that intelligence, skills, and talents are malleable, not fixed; with effort and persistence, these attributes can improve (Dweck, 2008). The very nature of the EDP presumes that one's engineering practice and understanding of the problem and solution is grown throughout the design process. Indeed, the EDP is arguably a learning process in which one fundamentally learns how to solve a problem and failure is an intentional part of that process. Persistence and effort are required, as one's first design is unlikely to be the most successful or is likely to fail. Failure is taken as information, as feedback, rather than as a personal assault, i.e.: "It is also relevant that designs fail (not students)" (Cunningham & Carlsen, 2014b).

Ideally, students who successfully navigate the engineering design experience have resilient responses to failure. Resilient responses include: persevering (i.e., not giving up in the face of disappointment or struggle); seeking to determine what went wrong; and using that information and other evidence to determine how to improve for their second or subsequent design. Non-resilient responses include giving up or incorporating a random change for a second or subsequent design rather than implementing a carefully thought out change based on evidence. Some have argued that failure serves as a natural catalyst—an intrinsic motivation—for students to figure out what caused a design to fail and what to do about it in subsequent design iterations (Barnett, 2005; Cunningham & Carlsen, 2014b). "Failure," states Kolodner and colleagues, "promotes a need to explain … so that he or she [the designer] can be more successful" (2003, pp. 502–503).

In reality, students provide a range of responses—from resilient to not resilient —to engineering design challenges (Barnett, 2005). Evidence in the literature suggests that teachers can create a climate and otherwise act to encourage resilient responses. Recall that an earlier argument by Ricci was that the teacher must establish a climate that supports a growth mindset in students. Similarly, the expert teachers in Rutland and Barlex's study of creativity development in design technology education were "clearly supportive of environments where fear of failure was not an issue" (2008, p. 158). Such an environment was described as "relaxed, calm positive, and secure … and essential to ensure that pupils ... have the confidence to take risks and try out ideas."

In a study of inner city students challenged to design underwater remote operated vehicles, Barnett shared that students initially reacted to the design challenge with "I can't do it" and "we will never get it done" (Barnett, 2005, p. 96). The teacher offered the following mini-lecture to the students:

> You know when I started, I had no idea how to do this. I even put the motor in backwards the first time! [Laughing from the students]. I wired the control box wrong, so when I pushed forward it went backward [more laughing]. Despite all that I got it done and so can you. I learned a lot in building my ROV and a lot from my mistakes. So don't worry about if you think you are going to make a mistake. What is the worst thing that can happen? (Barnett, 2005, p. 96)

This teacher modeled a growth mindset to students who had been firmly situated in non-resilience and a fixed mindset. The teacher described his failures and mistakes, shared how he persevered, and suggested that he was engaged in a learning process (not a demonstration of innate abilities). After this mini-lecture and subsequent discussion, "the students approached their work with a renewed sense of vigor and confidence that they could do it" (Barnett, 2005, p. 96).

Despite these examples of creating a climate for a growth mindset within engineering education—where failures are valued as crucial feedback and part of the learning process—there is much to be learned about how teachers perceive of failure and how they can support students as they fail

[3] See our other paper in this special issue of JPEER for critical thoughts about when analysis may be more challenging for students.

during engineering challenges.[4] The teacher's role as a facilitator of the EDP—and therefore a facilitator of failure experiences—is quite different than that of the traditional science teacher or the traditional technology teacher (Fortus et al., 2004; Rutland & Barlex, 2008). As Fortus and colleagues said of their Design-Based Science curricula, future work needs to "look … closely at the teachers' perspectives, their knowledge and experiences, how they adapt … curricula, and what kind of support they provide their students" (2004, p. 1099).

Conceptual Framework

This study employs a social constructivist worldview in which individuals make sense of their lives and worlds, developing "subjective meanings of their experiences … directed toward certain objects or things" (Creswell, 2014, p. 9). This sense making is influenced by the cultures and communities of practice in which individuals live and work (Sandaña & Omasta, 2017). Our interest in this study is on elementary teachers' sense making around failure experiences and fail words *before* they begin to teach engineering to their students. We assume that teachers' perspectives on failure are influenced not only by their personal experiences but also by the educational contexts in which they work, which as we have discussed, may position failure in a negative way, yet might also include more growth-minded perspectives on failure (Dweck, 2008). These perspectives—these ways of making meaning with respect to failure experiences and words—may be consistent or in conflict with the ways that failure experiences and words have been constructed in the context of engineering. Consistency and conflict are particularly interesting when the cultures of elementary school and engineering come together for elementary engineering education.

Although qualitative research questions and methods are ideal means of enacting this constructivist worldview, we simultaneously enact a pragmatic worldview in this study that allows for the collection of quantitative data to inform teachers' meaning making around failure. This pragmatic worldview creates ontological space for researchers to both provide a range of meanings and responses from participants *and* to test hypotheses (Creswell & Plano Clark, 2011). Data are gathered from qualitative and/or qualitative sources based upon what works to address the research questions (Creswell, 2014).

Research Questions

This mixed methods study examines the topic of failure in the classroom by elementary teachers new to teaching engineering. The research questions that guided the qualitative portion of the study were as follows:

1. How do teachers react to fail words?
2. What are teachers' perspectives on failure as a learning experience or as something to be avoided in the classroom?
3. To what extent and how do teachers report using fail words in their classrooms?

Also, three null hypotheses were used to quantitatively explore the extent to which teachers reported allowing their students to fail or allowing their students to revise their work:

H_{01}: Teachers with overall positive views of failure will report a similar frequency of "allowing students to fail" in their classrooms as teachers with overall negative views of failure.
H_{02}: Teachers with overall positive views of failure will report a similar frequency of "allowing students to revise their work" in their classrooms as teachers with overall negative views of failure.
H_{03}: Teachers will report a similar frequency of "allowing students to fail" in their classrooms as they report "allowing students to revise their work."

A convergent mixed methods approach was used in testing the first and second null hypotheses in that the "overall positive" or "overall negative" view of failure were generated via qualitative data analysis (Creswell & Plano Clark, 2011).

Methods

Study Context & Participants

This study is a part of the Exploring the Efficacy of Elementary Engineering (E4) Project. The E4 Project examines the impact of two engineering curricula on children's engineering learning, science learning, and interest in and attitudes towards careers in science and engineering. Also investigated within this larger study are teachers' conceptions about engineering and science instruction and their fidelity of implementation of assigned curricula. The E4 Project spans three states: Massachusetts, Maryland, and North Carolina. Since the time that this study was initially published (2014), the E4 Project has gathered data over the course of two academic years from over 250 teachers and 17,000 students.

Teachers were recruited to apply to participate in the E4 Project via the use of project flyers disseminated through state, district, and school level channels within the three regions. They were informed of study requirements, including: attending the aforementioned professional development; teaching their assigned engineering curriculum, along with their regular science units, for two years; completing implementation logs after each lesson; conducting and gathering

[4] Note that a version of this paper was originally published in the 2014 ASEE Annual Conference Proceedings. This statement regarding the need for more research on failure in engineering education was true in 2014, and, although the research base has grown, is still valid today.

student surveys and assessments; and completing surveys and other research instruments. Most teachers who applied to participate in the E4 Project were accepted, so long as they were eligible. Eligibility included that: they were currently teaching third, fourth, or fifth grade; they had not taught engineering extensively to students in the past (a few had taught some engineering design challenges, but had not explicitly used an EDP in their instruction); and the students that they would teach in the first or second years of the project would not have been exposed to formal engineering learning experiences in their schools prior to E4 Project instruction.

Between a three-day professional development to learn curricula and the onset of teaching during the first year of data collection, we selected a subset of teachers whose classrooms would be Classroom Intensive Observation (CIO) sites. In these classrooms, E4 Project team members: video-recorded classroom activity, including student team group dynamics; interviewed teachers before and after teaching for the first year of instruction, and again after the second year of instruction; and interviewed student teams. CIO site teachers were selected purposefully for a variety of factors, including that they: represented all three states; included teachers from both curricula; taught a range of the five units of focus within the study; represented a range of schools with respect to students' socio-economic status, location (rural, urban, suburban), and race/ethnicity; were relatively geographically proximate to the researchers who travelled to see all 10 hours of instruction per unit; were willing to have their classrooms be CIO sites; and were readily communicative with E4 Project team members. Scheduling issues were also relevant especially for two regions (Maryland and North Carolina) in which only one researcher per region was available to visit CIO sites; thus, if two teachers taught at the same time, only one of them could be selected for observation. Finally, and importantly, owing to whole-class video recording, CIO classrooms needed to have 80 percent or more students who received permission to be video-recorded. If this condition was not met, the teacher could not be selected for close observation owing to difficulties keeping students out of camera view.

The present study includes pre-professional development survey responses from most of the 257 teachers who participated in the E4 Project in the summer of 2013. This study also includes interview data from a subset of these teachers who were seriously considered for—and in some cases ultimately selected to be—CIO site teachers as the multiple factors for selection were considered. In all, 254 teachers responded to the pre-professional development survey, and 38 teachers participated in interviews.

Surveys

In the month prior to professional development, surveys were sent electronically to E4 Project teachers via an online survey program. There were three survey questions that were relevant to the present study. The response rate for these questions was quite high: 99 percent of E4 project teachers responded to failure questions. One question was in an open-response format and was as follows: What words/phrases come to mind when you think about the word, failure? Teachers responded to this question within a text box. The two other questions sought to examine the frequency with which teachers currently allowed students to: (1) "fail in your class" or (2) "revise their work (e.g., to redo and resubmit an assignment) in your class." Teachers responded according to the following Likert scale: Almost Always, Pretty Often, Once in a While, or Never.

Qualitative analysis of 254 responses to the open-ended question involved iterative generation of descriptive codes to capture positive and negative responses to the word, failure (Creswell, 2014; Saldaña & Omasta, 2017). A total of 30 codes emerged to describe the responses. Analysis of quantitative results (i.e., Likert-scale data) for the "fail in your class" question (254 responses) and the "revise their work" question (253 responses) involved a combination of descriptive and inferential statistics (Hinkle, Wiersma, & Jurs, 2003). In this paper, medians and frequencies of responses to Likert-scale questions were used given the non-parametric nature of the data. A Kolmogorov–Smirnov test was run to verify that the data were, largely, not normal. Mann–Whitney–Wilcoxon (MWW) tests were used to determine if there were differences in response between teachers who offered positive views of failure and teachers whose views were negative (de Winter & Dodou, 2010). Two-tailed significance at levels less than or equal to 0.05 were reported.

Interviews

E4 Project teachers whose classrooms were being considered as possible CIO sites were invited to participate in a semi-structured interview within approximately two months of receiving professional development and prior to teaching an E4 unit (Maxwell, 1996; Spradley, 1979). Most of the interview was about failure and related concepts; however, the interview protocol also included a few questions about science and engineering, and allowed teachers to discuss any questions or concerns that they had about the study. Overall, the average duration of the failure portion of the interview was 15 to 20 minutes.

The portion of the interview protocol utilized in this study began by asking teachers for their first reaction to the words fail or failure and then asking them to consider their reactions to and level of agreement with two statements: (1) some educators say that failure is to be avoided, and (2) some educators say that failure leads to learning. Finally, teachers were asked to what extent they use the words fail or failure in their classrooms.

Interviews were collected within all three states. In Massachusetts, due to logistical constraints, not *all* teachers

considered or selected for Case Study teachers were interviewed. A total of six interviews came from Massachusetts. These interviews were not audio-recorded, but rather, and although not ideal, the interviewer—an E4 Project staff member—took extensive notes during the course of the interview. All Massachusetts interviews were done via phone.

The interview process in Maryland was similar to that in North Carolina. In Maryland, the first author (Lottero-Perdue) conducted 14 interviews; seven of those were face-to-face and seven were done via phone. In North Carolina, the second author (Parry) conducted 19 interviews; five of those were face-to-face and 14 were done via phone. All interviews were digitally audio-recorded, with the exception of one North Carolina face-to-face interview for which audio recording did not occur due to technical difficulties. Thus, a total of 32 Maryland/North Carolina interviews were audio-recorded and later transcribed in preparation for analysis.

Prior to analysis, pseudonyms were assigned to all 38 interviewees. The 38 interview notes/transcripts were imported into HyperResearch™ qualitative analysis software. Qualitative analysis of the interview data involved iterative reviews of the transcripts to search for codes and sub-codes (Creswell, 2014; Tesch, 1990). Throughout this process, codes were identified, refined, and at times removed or renamed. Ultimately, a list of four codes and 27 sub-codes was used to code the interview data for this study. Although the intent of interview data was to add richness and description with regard to the range and complexity of teacher response, percentages of particular kinds of responses were used to give readers a sense of response frequency among interviewees. These numbers, however, are not meant to be interpreted with the same kind of statistical importance as are percentages for the aforementioned quantitative data.

Reliability and Validity

All survey items used in this study were used for the first time. Given the exploratory nature of this study, reliability was not calculated for quantitative items. We aimed to keep the survey questions quite broad so as to not impose a particular meaning of failure on participants. This was appropriate for the open-ended question, especially. One possible downside of the two quantitative questions is that they may have been overly broad, leading to such a wide range of interpretation as to be less meaningful overall.

Qualitative survey and interview questions are reliable in that we generated accurate transcripts, and kept accurate record keeping of codes throughout the coding process (Creswell, 2014). The second author (Parry) examined the analysis of the first author (Lottero-Perdue), and concurred with Lottero-Perdue's analysis based upon her (Parry's) interviewing experience within the study.

The qualitative survey and interview questions have content and construct validity. The questions were developed by the first author and iteratively reviewed and revised by E4 Project team members, all of whom have significant experience developing curricular materials, providing professional development, and working with elementary teachers as they learn to teach EiE units of instruction. With respect to construct validity, the survey and interview items were very directly related to the constructs we sought to measure. Also, the semi-structured nature of the interview enabled us to re-phrase questions for clarity if necessary.

Researcher's Roles

We are former engineers, and have extensive experience teaching engineering to pre-service and in-service elementary teachers. This collective experience enabled us to notice the different ways in which failure was perceived and positioned within engineering and elementary education communities of practice. We were Co-PIs on the E4 Project, and assisted with professional development that occurred prior to the interviews that we conducted. At this point in the study, prior to instruction, we were regarded more so as researchers than as participants in the teachers' classrooms. Although these experiences and roles have been helpful with regard to study design and analysis, and although we have been as careful as possible to represent participants' views in the data, our biases about failure and engineering and elementary communities of practice are unavoidable.

Findings

Study results are organized into five sections: (1) teachers' reactions to the words failure or fail, (2) teachers' perspectives on allowing students to fail or revise their work, (3) teachers' perspectives on avoiding failure, (4) teachers' perspectives on learning from failure, and (5) teachers' reported use of the words failure or fail in their classrooms. The first section is informed by both survey and interview data, the second is informed by survey data alone, and the final three sections are informed by interview data alone. To alleviate confusion regarding the data source, "respondents" will be used to refer to the teachers who responded to survey questions, while "interviewees" will be used to refer to those who participated in interviews.

Teachers' Reactions to the Words Failure or Fail

Both survey and interview data suggest that the words failure and fail have a largely negative connotation for most teachers; however, some teachers may also or exclusively associate these words with more positive descriptions and actions. By negative here, we mean detrimental,

Table 1.
Respondents' initial overall views of the words fail or failure from survey and interview data.

Overall View of Failure	% Survey Respondents (N = 254)	% Interviewees (N = 38)
Overall Negative	62%	61%
Overall Positive	17%	5%
Mixture of Negative and Positive	17%	34%
Unclear	3%	N/A

not constructive, pessimistic, or suggestive of behaviors that would be considered non-resilient in the face of struggle (e.g., giving up). Thus, by positive, we imply the opposite, i.e.: good, helpful, optimistic, or suggestive of resilient behaviors.

On the survey, teachers were asked: What words or phrases come to mind when you think about the word, failure? (Hereafter, this will be referred to as the "failure words/phrases question.") Each of the 254 respondents used between 1 and 7 words or phrases (median: 2) to answer the question. Most (62 percent) of the 254 teachers who responded to the survey question—offered entire responses that positioned failure as a negative event or behavior (Table 1). For example, one respondent shared: "I won't try that again / I can't do it / It won't work / I'm no good / I can't do anything right / Why try?" Alternately, 17 percent of respondents responded in an entirely positive way, for example: "An indication to regroup, revise, and try again!" Some responses (17 percent), however, were mixed, offering a more ambivalent view of failure. For example, one teacher offered: "Usually I associate failure with giving up. But only if you stop trying. Many of us have failures that result in learning." Finally, 3 percent of the entire responses were unclear with regard to having a positive or negative association.

During interviews, teachers were asked: What is your first reaction when you hear the words fail or failure in the context of education? Similar to survey responses, 61 percent of interviewees shared views of failure that associated failure or failing as being negative in nature (see Table 1). Only 5 percent of interviewees shared an exclusively positive view of failure, and the remainder—34 percent—offered both positive and negative views of failure.

In the two subsections that follow, we unpack the negative and positive categories for both survey and interview data to further examine teachers' perspectives on the words fail and failure. Within each of these categories were multiple codes that we describe in these subsections. In total, 17 negative and 11 positive codes emerged from 630 words/phrases shared by survey respondents.[5] Interview data included nine negative and five positive codes in response to the failure reaction question.

Negative Initial Perspectives on Failure

Over three quarters (81 percent) of all survey respondents and the overwhelming majority of interviewees (95 percent) offered at least one word/phrase or response that was coded as a being a negative perception of failure. Teachers answered questions about their perceptions of failure in general or with respect to their own failures, failures experienced by their students, or failures within the educational system.

Within the survey data, a total of 18 codes, including an "other" code for miscellaneous and otherwise un-coded contributions, were generated to describe negative words/phrases. These codes were then grouped into two categories or left alone as distinct categories/codes themselves. Categories included:

- Causes—suggested reasons why failure occurs;
- Non-resilient responses—sub-codes within the Causes category that may also represent responses to failure (e.g., giving up after failing);
- Descriptors—ways of describing failure or knowing that failure occurred;
- Identity—how individuals may identify as failures;
- Emotional responses to failure—how individuals feel when they fail; and
- Other—negative responses not coupled with two or more like responses.

Table 2 presents these categories and the associated codes for negative words/phrases shared in survey data. Interview responses that were identified as negative were associated with eight of the negative words/phrases codes: Giving Up; Not Trying/Not Putting Forth Effort (combined); Receiving Poor Instruction; Performance Indicators of Failure; Lack of Success; Not an Option; and Identity.

Table 2 summarizes the percentage of respondents that included a word/phrase for each of these categories, as well as for codes within the Causes and Descriptors category. Half of all respondents suggested a cause or non-resilient response. The most frequently mentioned causes or non-resilient responses (i.e., giving up, not trying, not putting forth effort) reference a lack of persistence, perseverance and resilience, and were echoed in some interviews. Eleven percent of interviewees suggested that failure was an indication that students were not trying or showing little effort (e.g., Barbara[6] shared that "failure is not even trying … that to me, is failure"). Eight percent of interviewees suggested that failure occurred when someone quits or

[5] In total, 641 words/phrases were coded. Of those, 11 were unclear and thus not deemed positive or negative.

[6] A pseudonym. All names used in the paper are pseudonyms.

Table 2.
Respondents' use of negative words/phrases within responses to the survey question: What words/phrases come to mind when you think about the word, failure?

Category	Code	% Participants (N = 254)
Causes		50%
*or Non-Resilient Responses	Giving up*	30%
	Not trying*	15%
	Not putting forth effort	9%
	Lacking knowledge or understanding	6%
	Not motivated	5%
	(Students) Receiving poor instruction	4%
	Task is too hard	4%
	Not enough support or resources	3%
	Bored or disengaged	3%
	(Students) Not given additional opportunities to succeed	2%
Descriptors		40%
	Performance Indicators of Failure	23%
	Association with Lack of Success	8%
	Unable to Do Something	7%
	Negative or Bad	5%
	Failure is "Not an Option"	5%
Identity		17%
Emotional Responses		17%
Other (Miscellaneous)		9%

gives up (e.g., Heather offered, "I think that if you fail something … it means that you have … thrown in the towel" and Sara stated, "Failure in my classroom is someone who chooses not to improve upon their mistakes").

A relatively small percentage of survey respondents (4 percent) shared words/phrases related to poor instruction, which was categorized as a Cause within Table 2. Instruction, however, was a significant topic in interviews. Over one third (34 percent) of interviewees shared that the words fail or failure called to mind the failure of a teacher to do their job, to help their students learn, or to help their students perform well on tests. For example, Kimberly said:

> I just automatically, when I hear that word, I just—it goes back to me. I think about us as educators … If we don't have an effective teacher in front of our children every single year, then I feel like we're failing our students. (Kimberly)

Interviewees suggested that they not only imposed this on themselves, but that others (e.g., parents, government, society at large) imposed this upon them. David, for example, shared that as an educator, he and his students were surrounded by benchmark tests, and that "if the kids can't pass whatever the proficiency test is, then we've failed them—teaching them the skills."

Over one third of survey respondents used words and phrases to *describe* failure and most of these (23 percent) provided indicators that failure occurred (e.g., "bad grades," "mistake," "incomplete," and "not performing to standards."). A comparable percentage of interviewees (26 percent) also made references to students failing either in general terms (e.g., Lauren mentioned "students passing or failing things") or with regard to specific assessments or assignments (e.g., Ashley's image of "a test with a big, red F at the top of it" or David's aforementioned reference to benchmark tests).

Both interviewees and survey respondents used other general negative descriptions of failure. Interviewees (18 percent) related failure to a general lack of learning or understanding for the student. This is evident in the following exchange with Debra:

> Interviewer: … What is your first reaction when you hear the words, fail or failure?
> Debra: [Pause.] I guess just not learning. You haven't learned it. [Pause.]

> Interviewer: And why is that—this is kind of a silly question—but why is that your first reaction?
> Debra: [Pause.] I guess 'cause that's our main goal for being here, and if that's not happening, and whether that's the student or the teacher or what's caused that to happen—you know, that's why we're here, so if you're considering yourself or someone else is considering you a failure or failing, you're not learning, you're not—getting what you're supposed to.

Survey respondents described failure as the opposite of success, an indication that one was not able, or simply "negative" or "bad."

The phrase "failure is not an option" or word "unacceptable" was used by 5 percent of the survey respondents as a response to the words fail or failure; in some survey responses, either "failure is not an option" or "unacceptable" was the only response to the failure words/phrases question. The phrase, "failure is not an option," was also used and described by 16 percent of interviewees offering their response to the words fail or failure. Interview data suggest that for those who describe failure as "not an option" or "unacceptable," failure is so negative that it was to be excluded as a way of experiencing education or the world at large. For Lori, who was frustrated when colleagues would allow students to fail courses or assignments, failure wasn't "in my vocabulary." She offered her students the time to "keep going, keep going, keep going—don't accept failure," a similar sentiment shared by Crystal who believed that "nobody fails if they keep trying." Diane and Teresa shared a different perspective. For them, failure was not an option because success was relative; "everybody," said Diane, "will succeed on a different level."

Approximately one sixth (17 percent) of respondents included a word or phrase coded as "identity" (e.g., "loser," "poor self-esteem," "dumb," "not good enough"). The same percentage of teachers described negative emotions affiliated with failure (e.g., "disappointment," "frustration," "sad," "feeling hopeless"). Although negative emotions were not coded separately within interviews, identity—specifically, the negative connotation of people or students identifying as a failure —was discussed by 32 percent of interviewees. Nicole, when asked for her first reaction to the words fail or failure on a personal level, answered: "Negative. Don't want to be one." Other interviewees referenced wanting to protect students from thinking of themselves as failures, as did Rachel when she made the following distinction: "It's okay to fail, but you're not a failure." The exchange with Meg, below, suggests an image of the dangers of failure-as-identity:

> Failure. Uh, I think it's a negative derogatory box that people have been put in … just when I hear the word failure that it is a box. It may be self-inflicted or you may be assigned, but that is a box you have been put in because once you get in that box, you don't have any incentive to get out of the box and you don't know how to get out of the box. I feel like I associate students being a failure as a negative. I know that everyone fails at some things but I just think it's a negative association. Coming from where my students come from—from their home lives, they come in already feeling like maybe they're a failure so I try to get them to think about it in a different way. (Meg)

As the interview with Meg continued, we learned more about why she was quick to consider this negative view of failure. She offered that as a child, "the negative connotation [of failure] was what was reinforced [by her community] ... that message of you fail, you're a failure, you're not good—and that's a hard thing to break."

Meg and many other interviewees (34 percent) provided personal responses when they gave their first reactions to the words fail and failure, and for all but one of these cases, these words had—at least at one point in time—a negative connotation in their lives. Teresa shared a negative failure label in the same way as did Meg, yet in Teresa's case, a former teacher reinforced the failure label. Some interviewees recalled perfectionist tendencies, wanting to be a "good girl, wanting to do it right," or being raised in households with very high expectations. Emily, Joy, and Noel felt that failure was unacceptable for them personally, but regarded it as a normal part of learning for children and their students. Emily stated her dual-standard position thusly:

> Ah, (laughing) I mean, as much as I hate to admit it, I hate to hear the word failure. You know. Umm, I, I mean, it's a fear of doing something wrong or failing. So I mean as hard as it is to admit, because like—I teach my kids that it's okay to fail, but personally I mean, I think it is a hard thing to overcome. (Emily)

In the next section, we explore more about positive perspectives of failure—like Emily's suggestion to her students that it's okay to fail—shared by teachers in surveys and interviews.

Positive Initial Perspectives on Failure

About one third of survey respondents (34 percent) included a positive word or phrase associated with failure in their response to the failure words/phrases question (Table 3). Similarly, 39 percent of interviewees shared a positive perspective on failure when asked for their initial reaction to the words fail or failure. Eleven codes emerged to organize positive words/phrases on surveys; these were organized into categories similar to codes for negative words/phrases. Interview responses were associated with five of the eleven positive words/phrases survey codes:

Table 3.
Respondents' use of positive words/phrases within responses to the question: What words/phrases come to mind when you think about the word, failure?

Category	Sub-Code	% Participants (N = 254)
Resilient Responses		24%
	Trying again	21%
	Analyzing to improve	8%
	Making changes and fixing mistakes	2%
Descriptors		22%
	Failure is a learning experience	15%
	Failure is an opportunity	8%
	Failure leads to success	4%
	Failure encourages perseverance	3%
	Role models / examples of learning from failure	2%
	Failure is acceptable	1%
Emotional Responses		1%
Other (Miscellaneous)		3%

Trying again, Analyzing to Improve, Making changes and Fixing Mistakes, Failure is a Learning Experience, and Failure is an Opportunity.

Nearly one quarter of respondents (24 percent) provided words/phrases that were grouped into the Resilient Responses category. This category captured responses that described positive, productive actions to be taken once failure has occurred. Failure as a signal to try again was the most frequent code across all positive codes and in the Resilient Responses category. Other responses grouped within this category included the need to engage in failure analysis for the purpose of improvement (e.g., "seeing failure as feedback, making changes," "see what went wrong and try again," "start trying to figure out how to tweak it for next time to make it better") or to change or fix mistakes ("make changes," "fix").

Respondents who described failure in a positive light shared that: failure is a learning experience (e.g., "learning from your mistakes," "failure is how we learn," "it is part of a learning system); failure is an opportunity (e.g., "opportunity," "an opportunity to learn, try again," "another chance for success"); failure leads to success (e.g., "can lead to success," "because I fail, I win," "failure is a path to success"); failure encourages perseverance (e.g., "if an outcome is undesirable, at times it encourages tenacity," "persevere"); role models and examples show us that we can learn from failure (e.g., "many inventions were discovered through failure," "Thomas Edison"); and failure is acceptable and normal ("it's okay to fail," "acceptance"). Few participants used positive emotional responses in their descriptions of failure. These responses tended to suggest that individuals should maintain a positive mindset in the face of failure (e.g., "keep your joy").

Interviews provided additional context regarding positive views on failure, with 26 percent of interviewees discussing the importance of resilient responses such as trying again, analyzing and improving, and making changes, and 29 percent describing failure as a learning experience or opportunity. Interviewees tended to share many of these ideas within their responses to the words fail and failure. For example, Amber responded as follows:

> Amber: My first reaction is opportunity to learn.
> Interviewer: Why is that your first reaction?
> Amber: Why? Because even when you're in a job or teaching it helps to have someone tell you how to do it better. You can't improve unless you experience failure. Failure is an experience that you're more likely to own yourself. Because if you do something and you fail at it, it's you who's done it and if you take that opportunity to learn from it, then that's growth.

In this exchange, Amber identified failure as an opportunity, and specifically as an opportunity to learn and grow. Further, she mentions improving, in this case by having another person assist in identifying "how to do it better." April associated the words fail and failure with improvement:

> When it comes to the failure thing, that means there is room for improvement, you know … somehow—we need to re-evaluate, to make an improvement that is needed, in order to move past the failure to make it a success.

April's emphasis is on having resilient responses of analysis and change when a failure signals the need to improve. Trying again was implied in Amber and April's

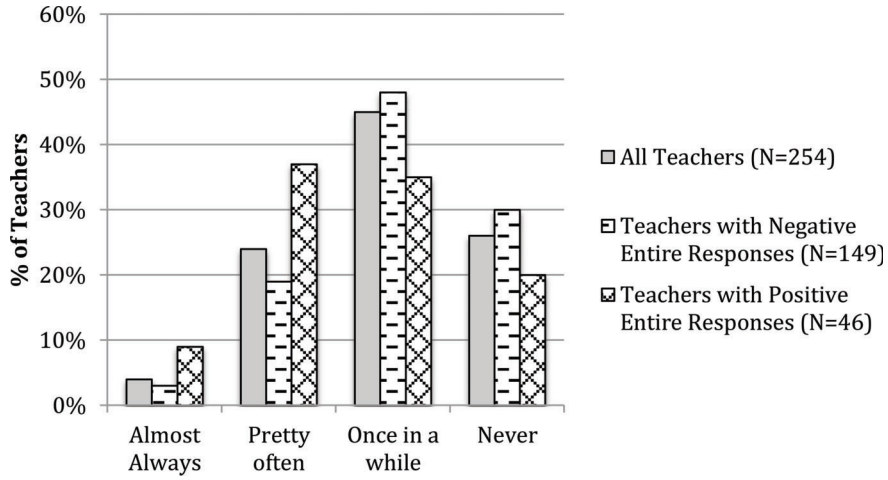

Figure 2. Respondents' answers to the question: How often do you allow students to fail in your class?

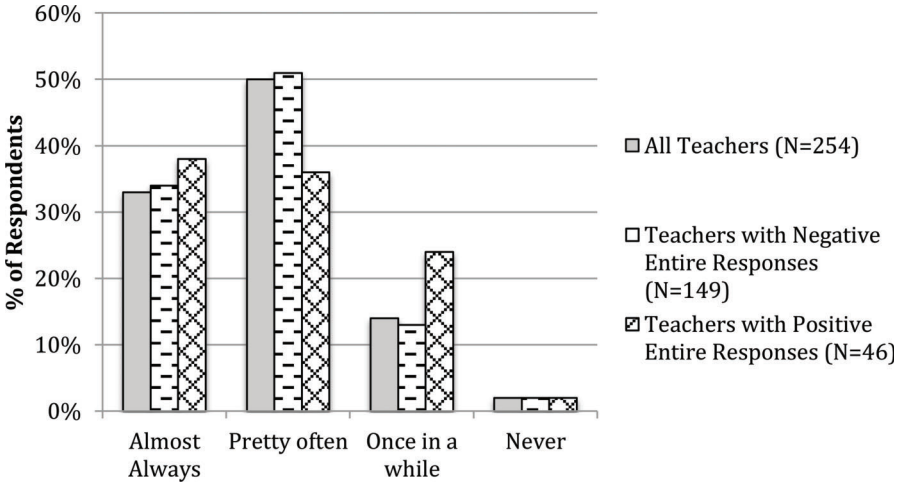

Figure 3. Respondents' answers to the question: How often do you allow students to revise their work in your class?

response, but explicitly stated by Tammy and others. Tammy responded to the question with: "My first reaction [is] 'Oh no!'" followed immediately by, "And my second reaction is failure only means that you tried and you may not have gotten the result you wanted but you can try again."

Teachers' Perspectives on Allowing Students to Fail or to Try Again

Recall from Table 1 that teachers' entire responses to the failure words/phrases survey question were coded as being overall negative (62 percent of teachers), overall positive (17 percent), mixed positive/negative (17 percent), or unclear (3 percent). In addition to answering the failure words/phrases question on surveys, respondents were asked to indicate the frequency with which they "allow students to fail" in their classes. Figure 2 depicts frequency responses to this question by all respondents and—separately—by respondents who had negative or positive entire responses to the words/phrases question.

Although the median response for all groups was "Once in a While," more respondents with positive entire responses to the failure words/phrases question selected "Pretty Often" than did those with negative entire responses. An MWW test comparing these two groups revealed that those with positive responses had a significantly higher frequency of reporting that they allow students to fail than did those with negative responses ($p = 0.009$), thus, rejecting null hypothesis H_{01}.

Teachers were also asked on the survey how often they "allow students to revise (e.g., redo and resubmit) their work." Results for this question are depicted in Figure 3. The median response for all groups was "Pretty Often." There were no significant differences across groups for this question, supporting H_{02}.

Respondents more frequently reported that they allowed students to revise their work (median = "Pretty Often") than they reported allowing students to fail (median = "Once in a While") (Figure 4). This difference is statistically significant with $p = 0.000$, rejecting H_{03}.

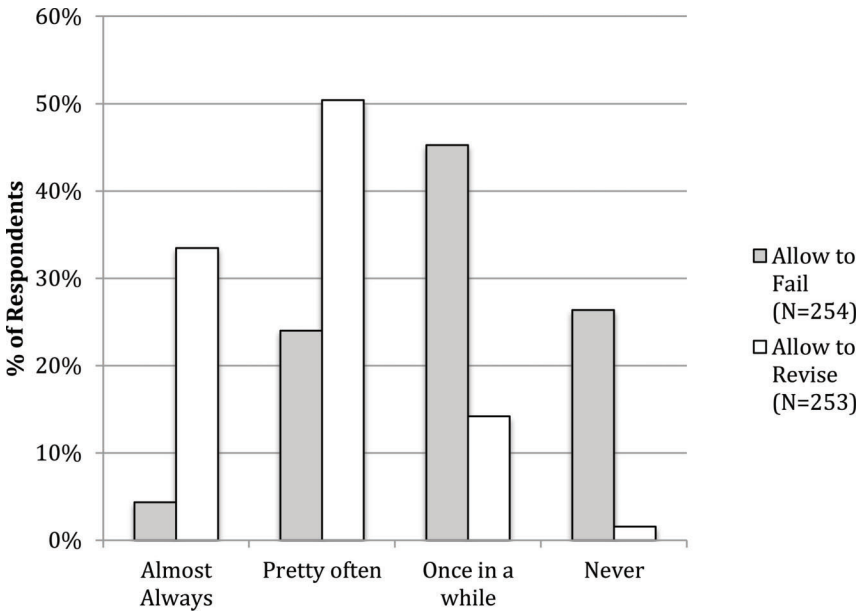

Figure 4. Respondents' answers to the questions: How often do you allow students to: (1) Fail in your class or (2) revise their work in your class?

Teachers' Perspectives on Avoiding Failure

After probing interviewees for their initial reactions to the words fail and failure, interviewees were asked to respond to and share their agreement or disagreement with the following statement: "Some educators ascribe to the idea that student failure should be avoided." In all, 71 percent of interviewees offered arguments that failure should be avoided either largely or in certain cases, and 66 percent provided arguments that failure should *not* be avoided in education. Clearly, there were some interviewees (37 percent) who were ambivalent, citing reasons to both agree and disagree with the statement. Approximately one third of interviewees either exclusively agreed (34 percent) or exclusively disagreed (29 percent) that failure should be avoided in education. Five codes were generated to describe the range of teacher responses: (1) agreement (i.e., failure should be avoided) with regard to avoiding student-as-failure identity; (2) agreement with regard to end-point failure; (3) agreement with regard to students with special needs; (4) other agreement; and (5) disagreement (i.e., failure should not be avoided).

Most of the interviewees who agreed with the statement specifically mentioned that failure should be avoided when it causes students to identify as failures. This sentiment was expressed by 37 percent of interviewees, like Roselyn, who shared: "I don't think that it's really okay to make kids think that they are a failure." Jason was concerned that too many failure experiences would lead to students assuming they cannot succeed (i.e., a failure identity): "if students fail and then continue to fail it will lead to them giving up and not trying because they assume they will not be successful." Jessica described the kind of failure to be avoided in education as "failure without hope," i.e.: "If it's the failure without hope, the kid who just goes home and thinks he can't learn, he's not smart, he starts to dislike school, then clearly, that is the kind of failure that we want to avoid." Two interviewees reminded interviewers that children may process words like fail or failure differently than do adults, and were concerned that children may be more likely to internalize failure language and experience as failure identities. Meg explained: "children don't hear things the same way that adults hear things and they internalize those pieces and that will become an identity that they can assume, and you don't want them to assume that identity." Brenda wondered at what age "it's okay to fail," and worried that young children's (e.g., first graders') self-esteem may be more fragile and unable to handle failure without internalization.

Another subset of interviewees (26 percent) juxtaposed what we will call "end-point" failures from "failures along the way," and suggested that end-point failures should be avoided. The following exchange with Lori—who was generally very welcoming of failure experiences in her classroom—exemplifies this well:

> So the failure at the beginning and, and during the middle process, that's why we do like little exit slips and we do little checks for understanding, you know, at that point all is good because then I can adapt. I can change. I can modify. But once you get towards the end and we're coming up to—"Okay. Time's up." —then we need to move on to the next content. That's why if it's still failure then yeah, that, that bothers me a lot.

It was this failure once "time's up" that was "not an option" in Lori's classroom. Kimberly similarly wanted to "allow some failure," but wished to avoid failing at the end

where "that's it—there's no picking up." David described end-point failure as "outright failure [which] should be avoided," and said later, "but I think initial failures are good because it teaches them new strategies and makes them stronger once they succeed."

Others who agreed that failure should be avoided mentioned backing off of failure experiences or providing more support for children with special needs, including emotional issues (5 percent of interviewees), or expressed general agreement that failure in the context of education should be avoided (17 percent). Melissa shared the general sentiment: "I guess every educator wants to avoid [failure]—you don't want your students to fail." Some mentioned that failing grades and failures on assessments like standardized tests creates unneeded, unhealthy pressure on children and teachers alike. Thus, students and educators aim to avoid these kinds of failures, which impact student progress through the educational system, as well as teacher performance evaluations.

Many interviewees disagreed that failure should be avoided in the context of education. While some offered general ideas about their disagreement or the value of failure as a learning experience (explored in the next section), others offered insights categorized here across four themes: (1) failure happens in the real world, so it should not or cannot be avoided in education (18 percent); (2) educators must prepare students to learn how to fail, not to avoid failure (18 percent); (3) the "trophy culture"—where everyone gets a trophy and no one loses or fails—is not a part of reality and is detrimental to students (13 percent); and (4) if educators are not challenging students and allowing for failure in their classrooms, then they are not appropriately educating them (16 percent).

Joy, who avoided allowing her students to fail in her early years of teaching and then learned the importance of failure in a STEM (science, technology, engineering, and mathematics) workshop session a few years ago, articulated the first two of these themes as she reflected on this transformative workshop:

> And so I think I really walked away from that session really thinking about, oh my goodness, I really need to set some of these kids up so that they could potentially, you know, fail, for lack of a better term. Because they need to understand that, you know, as a member of our society, things don't always succeed the first time around. For an adult it doesn't always happen the first time around. So if I'm just kind of sheltering them for success, later on in life when they meet failure, they might not know how to cope with it. They might not know how to problem-solve and be a diverse thinker.

Others offered that it is the job of educators to prepare students "to deal with it [failure] as opposed to avoid it" (Tammy). Considering what will happen if failure is avoided entirely in education, Kimberly wondered: "I actually think that you should allow students to fail. If a child is successful at every single thing—Good Lord … by the time they become a teenager or an adult and they finally have one failure, they might have a meltdown or a breakdown." Kimberly's wondering was articulated by interviewees who were concerned about the trophy culture where "everybody gets a trophy just for participating" (Brenda), "every single student has to get an award" (Ashley), or "we're not supposed to give them a grade below such and such" (Anita).

For some interviewees, avoiding failure was akin to avoiding educating students to their highest potential. April asked, rhetorically: "If you're trying to avoid failure, does that mean that you're lowering your standards, you know, bringing them, the expectations down, and not pushing the child to be their best?" Diane challenged those teachers who avoid failure experiences in their classrooms:

> Interviewer: What is your response to the statement: some educators believe that student failure should be avoided?
> Diane: I don't think they should be teaching. 'Cuz if you never fail, you never succeed. You, you just don't.
> Interviewer: So you would sort of see that as an absence of true learning? Because you mentioned earlier if you're not failing you're not learning?
> Diane: Right. No. I would, I would say that. But if you say that nobody should fail, then I think that you need—as an educator—to take an introspective look at yourself. Then, then why am I here? I am not here to make them feel good. I'm here to teach them and teach them how to learn. My job is to create thinkers.

Sara offered a related question: "if no one fails, why are we teaching them?" Similarly, Charlotte argued that educators should "push students into that fail zone, so that they can … move forward and learn more." These ideas are in line with the focus of the next section—teachers' perspectives on failure as a learning experience.

Teachers' Perspectives on Learning from Failure

Similar to the aforementioned statement about avoiding student failure, interviewees were asked to respond to and share their agreement or disagreement with another statement: "Some educators believe that failure leads to learning." All interviewees agreed with this statement. Four codes described the nature of interviewee agreement to the statement: (1) general agreement that we learn from failure (39 percent of interviewees), (2) the importance of challenging students (37 percent), (3) the importance of failure analysis (63 percent), and (4) failing as a means to teach perseverance (21 percent). All of these codes have been largely addressed within the "Positive Initial Perspectives on Failure" findings section thus far.

Interviewees who generally agreed with the statement provided insights similar to responses to the failure words/phrases survey question coded as Failure is a Learning Experience, Failure is an Opportunity, and Failure leads to Success. For example, Heather's response to the statement was:

> I totally agree with that because … when you see a student that has experienced failure, I think that gives them an opportunity to show growth, to show that they have the ability to comprehend and understand and to achieve and succeed on a path that they are undertaking. (Heather)

For Jasmine, failure experiences helped to create "fearless learners … [who] are able to embrace their failure and realize that it's not an end-all-be-all—that they can move forward from it, and … become better because of it."

The importance of challenging students was discussed in the previous section with respect to why some interviewees disagreed that failure should be avoided. In this section, comments from April, Diane, Sara, and Charlotte emphasized the importance of pushing and challenging students, with failure being an indication for the potential to learn and an absence of failure signaling that the proverbial bar is set too low. Tammy added in her response to the statement, failure leads to learning, that "it's important to let students struggle and try it on their own and a lot of times teachers find it necessary to let the kids get the answers right all the time." This inclination to scaffold learning to avoid failure was mentioned by Joy and others, who suggested that teachers are accustomed to scaffolding student learning to prevent failure. David and others mentioned the need to provide such challenges at an appropriate level, i.e.:

> You don't want them to get so frustrated where they don't want to try again. You want to make it challenging enough so they can fail and … redo it and come up with a different way and then ultimately succeed. (David)

Figuring out this particular point for students—the point where students can be challenged and learn, but not be too frustrated—was also mentioned by Diane, who shared: "I don't want a brilliant child crying every day because they're being pushed beyond their limits. But I don't want them sitting there either … not doing what they need … to learn things."

Just as a small percentage of survey participants mentioned that failure encouraged perseverance and tenacity, interview participants—responding to the failure-leads-to-learning statement—described the ways in which failure experiences help students practice perseverance. Interviewees shared that failure helped teach students "life skills like not giving up," "pick[ing] yourself back up," "to keep going," and "to keep trying and working at it." Sharyn referenced the "new idea" within the Common Core State Standards for students to "persevere and present them [students] with really hard problems"—to recognize that … [if] they've struggle through something … it is a such a more meaningful way to … learn things." David recalled the following story from his class, which was an example of perseverance in action:

> I had a student last year that would just, that had trouble with the homework and trouble with the seatwork and we kept using her as the model because she kept trying and kept getting better and by the end, she owned it. She knew where she had failed. She was so much stronger than the kids who either got it right away or who failed right away and just couldn't keep going.

Clearly, David's classroom is a place where it is safe to fail and to try again. Brenda mentioned the importance of such an environment in her response: "If the student is nurtured—and they are in a safe environment where it's ok to fail, and they are instilled with determination—then it would lead to learning."

The final category of response to the statement, "failure is a learning experience," were cases in which interviewees described some aspect of failure analysis and improvement, i.e., considering why the failure occurred, planning to improve upon the failure, and trying again to solve the problem. Nearly one quarter of interviewees (24 percent) described some way in which responding to failure or "mistakes" involved sorting out what went wrong. For example, Amber described this generally as "learning from what didn't work" and Hannah shared that failure was acceptable in the classroom so long "as you give them the opportunity to see why they failed [so] they can learn from it." Others described a reflective process in which students would ask questions of themselves like "What did I miss?" and "What did I do wrong?" For some, this was merely the first part of a process that would then involve planning to improve and trying again, as was evident in Denise's response to the learning-from-failure statement:

> I think of—You have that opportunity to … you made that mistake. Well, you have to learn from it and [ask] what did I do wrong? Now, let's—let's fix it. Let's improve on it. And so, you know—what do I need to do differently to make … it better?

Planning to improve or subsequently improving—e.g., in Kimberly's words, "turn[ing] this into a better solution"—was mentioned by 37 percent of interviewees. Interestingly, for Jessica, knowing how to improve called into question whether not a failure had actually occurred. This is evident in the following exchange:

> Jessica: It's probably not even a failure—if, when you don't succeed you already know what to do to make it better.

Interviewer: Oh, right—is that you're—so, you're posing the question: Is that really a failure?
Jessica: Right.
Interviewer: Right, if you already know?
Jessica: And my answer would be no, but then I wouldn't be answering your question, so … (laughing).

Mentioned earlier in the findings section, Jessica was concerned about students who experienced "failure without hope," but she saw failing (the verb) as a potential learning experience. In her mind, failure (the noun) was a hopeless end point, not part of a process. Thus, improving beyond a *failure* did not make sense. Teachers' use of the words failure and fail is the section to which we now turn.

Teachers' Use of the Words Failure or Fail in their Classrooms.

After discussing their initial reactions to the words fail and failure and sharing their perspectives on how failure may be construed as something to be avoided or a learning experience, teachers were asked the following question: Do you regularly use the words fail or failure in your classroom? For most interviewees (84 percent), the answer was "no" or "never" or "not regularly." For many, the question was somewhat jarring, and was initially met with silence or hesitation. This exchange gives a sense of this kind of response:

Interviewer: So do you use the word failure in your classroom—fail or failure —in your classroom regularly? And give me—an idea of how.
Jasmine: I do not. [Chuckles.]
Interviewer: Do not? Ok.
Jasmine: I realize after this conversation. I do not.

Although Jasmine, Emily, and many others did not use the words fail or failure at all, 14 percent of interviewees responded to the question with "not regularly." These teachers described the occasional instances in which grades were being handed out they mentioned "some of our class failed the test" (Sara) or "what you're doing right now is going to cause you to fail" (Ben). In one case, a teacher mentioned that she had used the word "failure" when an egg used in a design challenge cracked, but, said the teacher, "that's the only explicit time I've used that word."

Many interviewees (50 percent), including Jasmine and Emily, explained that the negative connotation that failure had within and outside of the educational community is what caused them to avoid using the words fail or failure. A similar percentage of interviewees (53 percent) supplanted the word failure for what they thought of as less loaded terms or euphemisms; in other words, according to April, "when it comes to a negative thing [like failure], I try to put a positive spin on it." Examples of replacements for failure, fail, and failing included: "made a mistake," "that answer was incorrect," "project didn't work well," "do your best," "we didn't get it," "being unsuccessful," "opportunities for improvement," "you're not learning," or "not your best effort."

While some interviewees simply shared that the words fail or failure were negative, or expressed what euphemistic replacements they might use, others provided more explanation regarding their choice to avoid those words. For example, Lauren shared the following in her interview:

Lauren: I would not ... I would say no. I don't say, you know, "This was a failure." I say, "This design didn't work, because it was lacking a base." Or we would talk about what didn't work. But I would not label a student's work or a group's work as a failure.
Interviewer: So why is that? What's your reason to avoid the word? Is it just that it isn't part of your educational vernacular, or is there a purposeful avoidance of the term? Do you know?
Lauren: I think it's kind of both. I think that I ... If somebody labeled something I did as a failure, it would hurt my feelings. So I don't know if it's the best word to use, especially with children.
Interviewer: Mmm hmm. (Affirmative)
Lauren: And you know, maybe it's something I need to learn to work in. I'm not sure. But I've never used it, because of the negative connotation.

Note that Lauren referenced the word fail*ure* in her response; so did David in his. Although neither David nor Lauren made an explicit distinction between the noun form of the word (i.e., failure) and the verb, to fail, others did. Adam and Anita articulated this well in separate interviews. Although they said that they did not use any fail words in their classrooms, they discussed the idea of using the words. Anita offered:

Because I think a lot of the kids, especially from the demographics that I have, I think they hear a lot of times that they are failures in a negative sense. And I don't want them to have that same connotation in the classroom. I don't want them to feel like they individually are failures, but that we all fail in the sense that that's a generic term. And that failing, that's ok. (Anita)

What Adam, Anita, and David all articulated is their concern that use of the word failure will not be interpreted as an external event, but rather as an identity taken on by the student.

There were some interviewees (16 percent) who said that they did use the words fail and failure regularly. Diane shared with her students that "failure is not an option"—and for her that means that everyone can succeed. Ashley, who teaches in a school and district where students are

constantly being pre-assessed, explained that "fail" is a regularly used word:

> I let them know that they are probably going to fail the pre-test, and that's okay … Every time I put a pre-test on their desk, they hear the word fail, because—that's the expectation—that they're going to fail. And I tell them, of course, if you do wonderful, that's great, but it's okay if you fail it. I mean, I pound that into their heads because I don't want them to be discouraged with the failure of the test. (Ashley)

Amber discussed the general concept that failure is a learning opportunity with their students, and Tammy let her students know that "if you don't get it the first time, this is a learning opportunity—if you fail, you get to try again." Lori and Rachel described a culture in each of their classrooms where it's okay to fail; however, there is one key difference. In Lori's case, the terms fail and failure are both "embraced": "If you try something and it's not the way it's supposed to be, I call it a failure." However, in Rachel's, although a constant message is "it's okay to fail," she does not use the word, "failure," for reasons described above by Adam and Anita.

Discussion and Conclusion

This study has attempted to break new ground by elucidating elementary teachers' perspectives about failure. Although there is much more to be learned on this topic, the following major conclusions from this study can be made:

1. A largely negative view of failure (in all of its word forms) is part of the historical tradition of education and part of many teachers' personal backstories; these histories influence teachers' responses to and use of the words fail and failure and whether/how they allow students to experience failure in the classroom.
2. Many teachers' analogue for 'experiencing and responding to failure in engineering' is 'experiencing and responding to mistakes'; this is both helpful and challenging to elementary engineering education.
3. Many teachers' perspectives on failure suggest that they have a growth mindset and create cultures in their classrooms to foster this; however, there are some challenges to true adoption of this mindset by teachers.

A discussion of each of these conclusions, as well as study implications and avenues for future work, follows.

The Negative Connotation of Failure

Survey and interview data suggested that a majority of teachers (roughly 60 percent or surveys and interviews) in the study had an overall negative view of failure, and that over 80 percent of survey and 95 percent interview participants offered at least some negative perspectives on failure. Further, nearly 85 percent of interviewees either never or rarely used the words fail or failure in their classrooms, and most of those avoided these words because of, as Lauren stated, "the negative connotation." In many respects, and as discussed earlier, this should be no surprise. Failure is not typically associated with good performance in schools, and reports of failing schools and failing students are unpleasant and do not position failure as a positive experience.

What is somewhat more telling from the data is many teachers' collective concern regarding students identifying as failures. This concern was mentioned by 17 percent of teachers (43 of 254) responding to pre-professional development surveys with the only prompting being, "What words/phrases come to mind when you think of the word, failure?" Student identity resurfaced in interviews when teachers provided their reactions to the words fail and failure, with one third of interview respondents voicing concern, and again by the same percentage of interviewees as they stated their disagreement with the statement, "student failure should be avoided." One previously shared example of failure-as-identity was this reaction to the words fail and failure from Meg: "the message of you fail, you're a failure, you're not good."

Recall that Dweck described those with a fixed mindset as assuming that "you were smart or you weren't, and failure meant that you weren't … struggles, mistakes, perseverance were just not part of the equation" (Dweck, 2008, p. 4). Meg and Teresa reminded us that teacher histories matter when they recalled aspects of their past that reinforced this fixed mindset, each describing boxes or labels that had been placed on them as failures, not smart, not good, not able. And although the teachers did not put it in these terms, their concerns about failure identity labels being taken on by their students were simultaneously worries that their students had fixed mindsets, unable to recover resiliently from something labeled as failure, and rather, taking on that failure identity.

The Mistake-as-Failure Analogue

Despite the aforementioned negative perspectives about failure by teachers in the study, all interviewees agreed that failure could be part of a learning experience. Such positive views of failure were offered by approximately one third of survey and interview participants as they reacted to the words fail and failure. As they explained these perspectives, they typically described fixing mistakes, having missteps and changing course, or not getting the result that you wanted and trying again. As discussed in the final findings section, teachers also used euphemisms like "made a mistake" to replace words such as fail and failure.

By relating failure to mistakes or errors—familiar occurrences in both teachers' personal histories and in the classroom—teachers were able to discuss and apply the importance of perseverance, evaluation, and improvement. These resilient responses were indicative of growth mindsets (Dweck, 2008), and were akin to the kinds of activities that one pursues in engineering failure analysis (Barnett, 2005; Cunningham & Carlsen, 2014b). However, there is a key difference between engineering failures and teachers' analogues of "mistakes." In educational settings, mistakes are typically regarded as errors in getting to a right answer—we make mathematical miscalculations, we misplace a comma, etc. Engineering failures during the EDP are expected parts of a process of innovating, learning, and moving towards a solution for which there is no right answer.

Teachers' Internal and External Practice of Growth Mindset

It has been suggested thus far that many teachers' positive perspectives on failure and ways of describing resilient responses to failure indicate that these teachers are likely to: (1) have a growth mindset (we will call this internal practice of growth mindset) or (2) create an environment in their classroom that encouraged students to take on a growth mindset (we will call this external practice of growth mindset). For example, teachers with overall positive views of failure according to the survey data are not as likely to be discouraged by failure. Throughout interviews, some teachers shared ways in which they personally persevered through struggle or learned as they gained life experience to see failure as an opportunity to learn, suggesting that they were firmly entrenched in the internal practice of growth mindset.

Study findings also suggest that some teachers encourage a growth mindset in their classrooms (Ricci, 2013; Silver, 2012). The finding that survey respondents with overall positive views of failure were statistically more likely than those with overall negative views of failure to "allow students to fail" is indicative that many of the "overall positive" response teachers were likely to encourage students to take on a growth mindset. In this way, teachers' potential fear of allowing students to fail was overcome by their recognition of the benefits that failure experiences can offer. David encouraged a classroom climate in which—as Rutland and Barlex shared in their paper—"fear of failure was not an issue" (2008, p. 158). As shared previously, David recalled guiding a student through multiple failures as she learned and relearned, and "by the end, she owned it [and] she knew where she failed." David seemed to employ an external practice of growth mindset in his classroom.

In other cases, however, there is evidence that although teachers describe real or envisioned growth-mindset classrooms, their responses to failure are more indicative of having an internal fixed mindset. Some teachers found failure acceptable for students, but unacceptable for themselves, which Emily articulated the following, shared earlier in the paper: "As hard as it is to admit … I teach my kids that it's okay to fail, but personally … I think it's a hard thing to overcome." This position is likely to make genuine modeling of growth mindset (and the perseverance, work effort, and resilience that characterize it), and thus teachers' external growth mindset practice, difficult for these teachers (Barnett, 2005).

Also, although teachers may have positive perspectives of failure as part of the learning process, even for these teachers there is some tension between: (1) the inclusion of failure experiences and (2) the deeply entrenched educational desire in the elementary education community of practice to set up or scaffold instructional conditions to ensure student success. Heavy scaffolding removes failure from students' learning experiences, and therefore may not help students develop perseverance, self-control, and ultimately, grit (Duckworth et al., 2007; Tough, 2012). Tammy, Joy, and other interviewees mentioned this tension (discussed in a previous section), which is may be a challenge to teachers who aim to encourage a growth mindset and thus resilient responses to failure in their students.

Implications and Future Work

Elementary teachers are at a potentially confusing intersection when it comes to failure. Assessment and accountability still loom large, with teachers, schools, and systems fearing failure on those assessments. Further—as was discussed by interviewees Lori and Ashley—there is a new and vigorous emphasis on pre-assessment, where failure is expected and even applauded. Importantly, engineering education is asserting its place in elementary education and aiming to create authentic engineering experiences for students. Failure has a different meaning in each context: with regard to large and "final" assessments, it is suggestive of a lack of understanding and poor instruction and is to be avoided; in pre-assessment, failure suggests lack of understanding, incorrect answers, and mistakes, albeit, those answers can be "fixed" with the learning that follows; and in engineering design, it's a normative condition and an expected part of the process.

Engineering educators who aim to introduce teachers to failure with respect to engineering must understand that repurposing this word for engineering is not straightforward and that redefining failure for engineering is not simply a semantic shift. Redefining, repositioning, and relearning words like failure, fail, or failing, is, rather, a cultural shift. The negative connotation of failure in the context of education is quite real and not to be dismissed. Failure is an extremely loaded word for some individuals, eliciting images and memories of inadequacy and fear. Failure is not just a condition; for some it's an identity.

Careless use of the word failure and its associated word forms may cause fear and anxiety in teachers and students alike—conditions that no teacher, teacher educator, or professional development providers would want those whom they teach to assume.

In addition, failure has the same problem as do words such as technology or theory, which have different meanings in colloquial language than they do in communities of engineers or scientists. As mentioned earlier, teachers tend to equate failures with mistakes or errors. In one respect, professional development providers and teacher educators teaching engineering to current and future teachers can capitalize on the familiarity of the benefits of resilient responses such as perseverance when students struggle and make mistakes. However, the caveat is that these educators must also delineate the differences between mistakes and engineering failures during engineering design. One way to do so would be to emphasize that the EDP builds in failure via iteration (Cajas, 2001). Another way would be to incorporate testing to failure within the EDP, and to explicitly discuss how the failure is an intentional part of the process to gather feedback (and is not a misstep or mistake).

Further, engineering educators may do well to explicitly address growth versus fixed mindset in teacher professional development and pre-service coursework; likewise, teachers can teach students about the malleability of intelligence (Ricci, 2013). Aforementioned research supports that this has multiple advantages (Blackwell et al., 2007; Good et al., 2012; Yeager & Dweck, 2012; Good, Aronson, & Inzlicht, 2003). This seems likely to assist those learning to engineer in overcoming fear of failure, practicing resilience and perseverance, and over time, perhaps, applying these strategies more broadly in life to develop grit (perseverance over the long haul). Further, engineering teacher educators could engage teachers in discussions of both the merits and the potential downsides of scaffolding or, as Joy said, "sheltering [students] for success."

There are many avenues for future work to expand and enhance the findings of this study. We aim to continue to investigate failure within the E4 Project, examining students' responses to failure during the design process, teachers' anticipated and actual responses to student failure, and teachers' reflections on failure after teaching engineering curricula over one or two years.[7] We, in particular the first author, will continue to investigate the intersection of growth mindset and engineering among students and teachers.

There is much work to be done beyond our planned efforts with regard to failure in engineering education. Our work focuses on third through fifth grade teachers and students, but we wonder how failure is perceived and experienced by other teachers and students, e.g., teachers of younger children, young children themselves, teachers of middle school students, middle school students themselves, etc. Also, demographic and gender differences in perceptions of and responses to failure should be explored (e.g., Do girls respond differently to failure than do boys? Do students in high needs schools perceive of failure in a different way than do students in affluent schools?).

[7] Many of these studies have been conducted since the time of this original publication.

Acknowledgments

The original version of this paper was previously published in the Proceedings of the 2014 American Society for Engineering Education (ASEE) Annual Conference & Exposition. This paper was awarded Best Paper for the 2014 ASEE Annual Conference and Exposition, and reprinted—with some changes and some updated citations—here in this special JPEER collection of recent Best Papers from the Pre-College Engineering Education division. This material is based upon work supported by the National Science Foundation under Grant No. 1220305. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors wish to thank the teachers who participated in the survey and interviews for their insights. Thanks also to the E4 Project team for their support, especially Christine Cunningham, Cathy Lachapelle, Jonathan Hertel, Chris San Antonio-Tunis, Kristin Sargianis, and Shannon McManus. We also appreciate the transcription support provided by Tiffany Childress.

References

Barnett, M. (2005). Engaging inner city students in learning through designing remote operated vehicles. *Journal of Science Education and Technology*, *14*(1), 87–100. http://www.jstor.org/stable/40188702

Berliner, D. C. (2011). The context for interpreting PISA results in the USA. In, *PISA Under Examination*, (11), 77–96.

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, *78*(1), 246–263. http://www.jstor.org/stable/4139223

Blumenfeld, P. C., Soloway, E., Marx, R., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3), 369–398.

Brickhouse, N.W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research on Science Teaching*, *38*(3), 282–295.

Cajas, F. (2001). The science/technology interaction: Implications for science literacy. *Journal of Research in Science Teaching*, *38*(7), 715–729. doi:10.1002/tea.1028

City Technology Project. (2013). http://www.citytechnology.org/node/1241

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Creswell, J.W. & Plano Clark, V.L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Cunningham, C. M. (2009). Engineering is elementary. *The Bridge, 30*(3), 11–17.

Cunningham, C. M., & Carlsen, W. S. (2014a). Teaching engineering practices. *Journal of Science Teacher Education*, *25*(2), 197–210. doi: 10.1007/s10972-014-9380-5

Cunningham, C. M., & Carlsen, W. S. (2014b). Precollege engineering education. In N. Lederman (Ed.), *Handbook of research on science education* (pp. 747–758). Mahweh, NJ: Lawrence Erlbaum Associates, Publishers.

Cunningham, C. M., & Lachapelle, C. P. (2014). Designing engineering experiences to engage all students. *Engineering in pre-college settings*: *Synthesizing research, policy, and practices* (pp. 117–142). West Lafayette, IN: Purdue University Press.

Delatte, N. (2009). *Beyond failure: Forensic case studies for engineers*. American Society of Civil Engineers: Reston, VA.

de Winter, J. C. F., & Dodou, D. (2010). Five-point Likert items: T test versus Mann-Whitney-Wilcoxon. *Practical Assessment, Research & Evaluation*, *15*(11), 1–12. http://pareonline.net/pdf/v15n11.pdf

Duckworth, A. L., Peterson, C., Matthews, M. D., & Kelly, D. R. (2007). Grit: Perseverance and passion for long-term goals. *Journal of Personality and Social Psychology*, *92*(6), 1087–1101. doi:10.1037/0022-3514.92.6.1087

Dweck, C.S. (2008). *Mindset: The new psychology of success.* Ballantine Books: New York.

Dweck, C. (2015, September 22). Carol Dweck revisits the 'Growth Mindset.' *Education Week*. Retrieved from http://www.edweek.org/ew/articles/2015/09/23/carol-dweck-revisits-the-growth-mindset.html

Engineering is Elementary (EiE) (2011). *A sticky situation: Designing walls*. Boston, MA: National Center for Technological Literacy.

Favero, N., & Rutherford, A. (2016). For better or worse: Organizational turnaround in New York City schools. *Public Management Review*, *18*(3), 437–455. doi:10.1080/14719037.2014.999819

Fortus, D., Dershimer, R. C., Krajcik, J. S., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081–1110. doi:10.1002/tea.20040

Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescent's standardized test performance: An intervention to reduce the affects of stereotype threat. *Journal of Applied Developmental Psychology*, *24*(6), 645–663. doi:10.1016/j.appdev.2003.09.002

Good, C., Rattan, A., & Dweck, C.S. (2012). Why do women opt out? Sense of belonging and women's representation in mathematics. *Journal of Personality and Social Psychology*, *102*(4), 700–717. doi:10.1037/a0026659

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003). *Applied statistics for the behavioral sciences*. Boston, MA: Houghton Mifflin.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of the Learning Sciences*, *9*(3), 247–298. http://www.jstor.org/stable/1466843

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design into practice. *Journal of the Learning Sciences*, *12*(4), 495–547. http://www.jstor.org/stable/1466914

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Levy, S. T. (2013). Young children's learning of water physics by constructing working systems. *International Journal of Technology and Design Education*, *23*, 537–566. doi: 10.1007/s10798-012-9202-z

Maxwell, J. A. (1996). *Qualitative research design: An interactive approach*. Thousand Oaks, CA: Sage Publications.

Murphy, J., & Meyers, C.V. (2008). *Turning around failing schools: Leadership lessons from the organizational sciences*. Corwin Press: Thousand Oaks, CA.

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press. doi:10.17226/13165

National Academy of Engineering (NAE) and NRC. (2009). Engineering in K-12 Education: Understanding the Status and Improving the Prospects. Washington, DC: The National Academies Press. doi:10.17226/12635.

NAE and NRC. (2014) STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research. Washington, DC: The National Academies Press. doi:10.17226/18612.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. www.nextgenscience.org/next-generation-science-standards. doi: 10.17226/18290

Nicolaidou, M., & Ainscow, M. (2005). Understanding failing schools: Perspectives from the inside. *School Effectiveness and School Improvement: An International Journal of Research, Policy & Practice*, *16*(3), 229–248.

Petroski, H. (2012). *To forgive design: Understanding failure*. The Belknap Press of Harvard University Press: Cambridge, MA.

Ricci, M. C. (2013). *Mindsets in the classroom: Building a culture of success and student achievement in schools.* Prufrock Press, Inc.: Waco, TX.

Rutland, M., & Barlex, D. (2008). Perspectives on pupil creativity in design and technology in the lower secondary education curriculum in England. *International Journal of Technology and Design Education*, *18*, 139–165. doi:10.1007/s10798-007-9024-6

Saldaña, J., & Omasta, M. (2017). *Qualitative research: Analyzing life*. Thousand Oaks, CA: Sage Publications, Inc.

Silver, D. (2012). *Fall Down 7 Times, Get up 8: Teaching kids to succeed.* Corwin Press: Thousand Oaks, CA.

Spradley, J. (1979). *The ethnographic interview*. New York: Holt, Rinehart, & Winston.

Tesch, R. (1990). *Qualitative research: Analysis types and software tools*. New York, NY: Falmer.

Tough, P. (2011). What if the secret to success if failure? *The New York Times*. September 14, 2011.

Tough, P. (2012). *How children succeed: Grit, curiosity, and the hidden power of character*. Boston: Mariner Books.

Yeager, D. S., & Dweck, C. (2012). Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational Psychologist 47*(4), 302–314. doi:10.1080/00461520.2012.722805