Scaffolding for Failure

Helping Students Navigate Engineering Design Failure

By Pamela Lottero-Perdue and Elizabeth Perry

Although teachers are accustomed to scaffolding students for success, teachers can and should also scaffold for failure by helping students develop a growth mindset in the context of engineering and beyond (Dweck 2008). When students enact this growth mindset, they learn from their setbacks and come to see that failures are opportunities to learn where and how we can grow and improve.

In this article, we share strategies on how teachers can support students as they develop productive responses to failure within engineering design experiences. Design failure is neither rare nor something to be avoided as students engage in science-integrated engineering design challenges as a part of the *Next Generation Science Standards* (NGSS Lead States 2013). In high-quality engineering education, students use an engineering design process (EDP) when they engage in design challenges (NAE and NRC 2009). There are many EDPs used in elementary classrooms; some crafted for younger or older elementary students, and others developed for particular engineering curricula (e.g., Engineering is Elementary 2018). What these EDPs have in common is that they:

- emulate what real engineers do when they solve problems; and
- have a built-in assumption that early designs are likely to fail, so it is necessary to try not just once but multiple times to solve the problem.

We see evidence of this second point in steps like "Improve" or "Try Again" in EDPs (e.g., see two different EDPs in Table 1).

For the last five years, we have investigated the responses of upper-elementary students and teachers regarding their experiences with engineering design failure and have asked them about how they use and think about failure terms (e.g., *fail, failed, failure*). We are often asked, "What advice do you have for teachers based on your research?" Although our study continues, we have some answers to this question. We have summarized these into 10 suggestions organized into two sections:

1. suggestions about fail words and their meanings; and
2. suggestions about preparing students for design failure and helping them respond to it during the EDP.

In addition, we have created a classroom vignette, "Staying Alive!" (see NSTA Connection) to put these tips into context. Although the teacher in the vignette, Mrs. Klein, is fictional, she is an amalgamation of the excellent teachers we observed and from which we learned over the years.

FAIL WORDS AND THEIR MEANINGS

1. Have explicit discussions with students about fail words and their meanings in different contexts.

Our interviews with students suggest that by the time students are in their upper elementary years, it is quite likely that they have heard or used fail words both in and outside of school. Teachers, coaches, parents, and others have used fail words in their presence, and many have used fail words themselves. In examples provided by students, fail words were used to indicate that something did not work or go as planned (e.g., a goalie was unable to stop a ball from going into the goal), or less often, that *someone* was a failure.

Before using fail words in engineering instruction, we suggest teachers have discussions with students about fail words and their meanings. Teachers might start by asking students in a whole-class discussion what fail words they have heard and what "fail" means in those contexts, and then present the specific way in which fail words are used by engineers and will be used in the context of engineering design challenges in the classroom (see #2).

2. Present a definition of design failure as: when a design does not perform against one or more criteria.

For engineers, design failure is about how a design performs against criteria, the standards used to determine the success or failure of the design. Those criteria are typically established prior to the development or testing of that design. For example, before designing a system to clean up an oil spill on a model river, students understand that the criteria include:

1) that less oil on the water's surface, as measured by a particular tool, is better;
2) that less oil on the shoreline, as

measured by a different tool, is better; and

3) that less expensive clean-up processes are preferable (EiE 2018).

A design failure may occur, for example, if too much oil reaches the shoreline. Design failures are determined objectively and are closely connected to criteria. In this way, they provide valuable information about how a design may be improved.

3. Always associate failure and fail words with designs and criteria, not with students or teams.

Early in our research, we asked elementary teachers if they used fail words in their classrooms. An overwhelming majority of teachers did not, or only used the words rarely and with respect to ideas about studying so as not to fail a test. In interviews, teachers shared that they avoided using fail words because they worried that students would internalize them, taking on failure identities (e.g., thinking that "I failed" or "I am a failure"). Even though teachers who taught engineering design challenges for two years became more comfortable using fail words and helping students navigate design failure experiences, some remained concerned that students may adopt failure identities. For this reason, we urge teachers to explicitly refer to design failure, not team or student failure. For example, a question to ask after the design testing process would be: "Did any of the designs fail to meet criteria?" rather than "Did any teams fail?"

4. Avoid clichés about failure to avoid confusing students.

We have seen multiple classroom posters about failure and heard many failure clichés in our work in schools. Although the intent of using them is meant to be positive, clichés can be problematic. Three examples are as follows:

Failure Is Not an Option: Failure is indeed an option—and a normal and informative one—in the context of engineering design failure. One need only look to the multiple failures of the SpaceX program, headed by Elon Musk, to see that failure happens, informs future work, and gets the company closer to the possibility of reusable rockets to deliver goods to the space station. One of the teachers in our study who had a "Failure is not an option" poster eventually took it down after realizing its message was not consistent with the idea that failure is normal and informs next steps in engineering (and in life).

You Only Fail if You Quit: Another teacher repeatedly told students that they only fail if they give up to encourage them to persevere. Although this was intended to be motivational, student interviews revealed that this presented a confusing message. One team, for example, could not come to consensus about whether their design failed because: (1) their design did fail to meet criteria, but (2) they tried again to improve their design (i.e., didn't give up, and thus according to their teacher, did not fail).

TABLE 1

Example Design Process actions.

	Engineering Design Processes (EDPs)	
EDP Actions	**Early Childhood (Lottero-Perdue et al. 2016)**	**Elementary School (EiE 2018)**
1. Defining the problem	Ask	Ask
2. Researching the problem and considering background knowledge		
3. Brainstorming design ideas	Imagine	Imagine
4. Selecting a design idea	Try	
5. Planning the design		Plan
6. Creating or implementing the design		Create
7. Testing the design		
8. Analyzing test results and considering improvement	Try Again	Improve
9. Iterating (i.e., repeating earlier steps of the design process and trying again to solve the problem)		

FAIL = First Attempt in Learning: The problem with this acronym is that quite often, engineering designs fail subsequent times, too, as some teams in our studies discovered. Having a design fail more than once is quite normal. For the developers of the Formula 409 cleaning spray, the first 408 designs failed (Formula 409 2017)!

5. Differentiate design failures from mistakes.

It may be tempting to associate design failures with mistakes. In the process of learning, students regularly make mistakes in their work, learn from those mistakes, and then improve their work. However, engineering design failures are not the same as mistakes. Mistakes are typically regarded as errors in getting to the right answer; once fixed, the right answer is achieved. The design process expects that design failures will not only occur but will provide valuable information to improve subsequent designs. In addition, there is no one correct answer in engineering design; there are multiple ways to solve a problem.

PREPARING FOR AND RESPONDING TO DESIGN FAILURE WITHIN THE EDP

6. Remind students about constraints, criteria, and testing procedures before the design process. Model proper testing procedures and discuss why they're important.

The constraints of an engineering design challenge are the limitations or restrictions placed on the design. For example, perhaps only certain materials can be used. Criteria inform students about how to create a successful design. Designs are often tested to inform criteria (e.g., a model bridge is tested by piling weights on top of the bridge until it fails). To ensure that students understand the constraints, criteria, and testing process, engage in discussions about these design elements *before* students begin to brainstorm or plan their designs and *before* they test their designs. Teachers can also model design-testing procedures for students. If students and teams do not follow the constraints, criteria, and testing processes, it will be difficult for them to accurately assess whether their design failed or succeeded to meet the criteria.

7. Prepare students for the likelihood that designs may fail, and that this is a normal part of engineering.

Prior to design testing, remind students that in engineering, it is normal for first and early design attempts to fail to meet criteria. Likewise, teachers should reference the EDP to show students that it allows for design failure because it involves multiple opportunities to improve. Engineering is about innovating, which means that

TABLE 2

Summary of students' responses to design failure (Lottero-Perdue and Parry 2017).

Positive responses	Negative responses
Acknowledging design failure when it occurs	Denying that failure occurred by ignoring proper testing processes
Trying again	Giving up or losing interest Seeing the task as being too difficult
Engaging in failure analysis	Making changes to design without planning or thinking carefully
Focusing on improvement	Staying with the original failed design
Working effectively as a team, seeking help from peers, and looking at other teams' designs	Engaging in negative team dynamics, focusing on competition (worrying about performing less well than other teams)
Using the EDP to guide next steps, referencing background information to inform next steps	Ignoring background information that could inform next steps
Asking for help from the teacher	Seeking the "right answer" from the teacher
Positive emotions/identities	**Negative emotions/identities**
Expressing a positive emotion, not appearing to take on a failure identity	Expressing a negative emotion/failure identity, appearing not to care

engineers often do not have a quick path to a successful answer.

8. Be prepared for a wide range of student responses to failure, both positive and negative.

Students' negative responses to design failure included blaming other team members or making changes to the design without careful thought or planning. However, students also had many positive responses to design failures, including engaging in failure analysis and focusing on how to improve. See Table 2 for a summary of both categories of responses. Be prepared for this range of responses so that you can anticipate how you might or might not intervene.

9. Do not intervene. Give students time to work through their own productive responses to design failure.

Students must try to "work it out" for themselves when confronted with a design failure. Teachers from our study talked about the need to let students work together as a team as they consider and analyze the failure, and then figure out how to improve. These teachers would monitor their teams—walking by, pausing, and listening—but did not always intervene to allow students to make progress in the design process. Even initially negative responses to failure, such as frustration, could be worked out without teacher interventions to allow students to move toward more productive responses.

10. Intervene when student teams become stuck on a design failure.

During teachers' monitoring of teams during and after the testing process, it became evident that some students and teams had become "stuck" in a negative response. In these instances, teachers' primary strategy was to intervene with the following questions to move teams in more productive directions. Students were:

- prompted to engage in failure analysis and consider how to improve (e.g., What were your testing results? How can you improve in your next design?);
- encouraged to be considerate to their peers, and to use peers within and outside of their team as resources (e.g., What do each of you think? How did other teams in the room try to solve this problem?); and
- provided help to make connections to critical background information (e.g., What did we learn about the needs of plants earlier in the unit that might inform your design of your plant package?).

Additionally, teachers reminded students that it is okay that their design failed to meet criteria and that the EDP enables them to improve. Finally, in rare situations when questioning strategies did not work, teachers described that they provided more direct advice to student teams when they were stuck or frustrated. This direct guidance (e.g., focus on improving your bridge supports) was a last resort to help student teams move forward in the design process.

DEVELOPING A GROWTH MINDSET BEYOND ENGINEERING

The above suggestions come from our work in science-integrated engineering education. However, the big growth mindset idea here—that failure is normal and gives us feedback about how to improve—can be applied to other subject areas and to life, in general. We observed this in our study, especially after teachers entered their second year of teaching engineering. This big idea about failure and improvement began to be interwoven throughout the school day: in science, mathematics, literacy, and other areas of instruction. ●

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NSTA Connection

Download the classroom vignette at *www.nsta.org/SC1903*.

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