



Elementary Teachers' Reported Responses to Student Design Failures

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Elizabeth Parry is an engineer and consultant in K-12 Integrated STEM through Engineering Curriculum, Coaching and Professional Development and a Coordinator and Instructor of Introduction to Engineering at the College of Engineering at North Carolina State University. For the past sixteen years, she has worked extensively with students from kindergarten to graduate school, parents, preservice and in-service teachers to both educate and excite them about engineering. As the Co-PI and project director of a National Science Foundation GK-12 grant, Parry developed a highly effective tiered mentoring model for graduate and undergraduate engineering and education teams as well as a popular Family STEM event offering for both elementary and middle school communities. Parry is currently a co-Pi on two NSF DR-K12 Projects: the Exploring the Efficacy of Elementary Engineering Project led by the Museum of Science Boston studying the efficacy of two elementary curricular programs and Engineering For All, a middle school project led by Hofstra University. Other current projects include providing comprehensive professional development, coaching, culture change and program consulting for multiple K-8 integrated STEM schools across the country, serving as a regional Professional Development for the Museum of Science, Boston's Engineering is Elementary curriculum program; and participating in the Family Engineering project. In June, 2014, Liz was appointed by the Board of Directors of the American Society for Engineering Education (ASEE) to chair a new committee on K-12 Engineering. She is the Immediate Past Chair of the ASEE K-12 and Precollege Division; serves as the Vice President of the executive board of the Triangle Coalition for STEM Education, is a board member of the STEM Consortium and is a member of the K-12 Advisory Committee for the American Society of Mechanical Engineering. The past three years, Liz has been named a member of the USA Science and Engineering Festival's "Nifty Fifty" program, a select group of notable scientists and engineers invited to give keynote presentations in advance of the festival. She has authored or co-authored over 35 papers on issues relating to K-20 integrated STEM, including "Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering," (co-author with Dr. Pamela Lottero-Perdue of Towson University) which was awarded Best Division (K-12 and Precollege), Best PIC (IV) and Best Overall Conference paper for ASEE in 2014. Liz is a frequent invited keynote speaker both nationally and internationally. Prior to joining NCSU, Liz worked in engineering and management positions at IBM Corporation for ten years and co-owned an informal science education business.

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Introduction

The inclusion of engineering design within elementary education means that students' engineered designs will sometimes fail. Failure is a normal part of engineers' and students' attempts to solve a problem by creating and testing possible designed solutions (i.e., designs); it is expected that one or more designs will fail to solve the problem and operate as intended.^{1, 2, 3, 4} Although students may receive failing grades or perform poorly on a test, failed *designs* are relatively new artifacts within elementary education.^{5, 6} One challenge for elementary teachers, then, is how to respond to students once design failure has occurred. This exploratory study examines teachers' reports of: students' responses to design failure, and teachers' own responses to students whose designs have failed.

Despite the acknowledgment by engineering and science educators that failure is a normal outcome of engaging in engineering design,^{7, 8, 9, 10} there is a dearth of studies that focus on failure in the context of pre-kindergarten through Grade 12 (P12) engineering education. One recent study examined elementary teachers' perspectives on failure prior to teaching an engineering unit of instruction.⁵ The study found that while these teachers may regard failure as a learning opportunity, few use words like fail or failure in their classrooms. Other studies and accounts of classroom experiences have addressed failure in that they include students generating failed designs, testing designs to failure, or conducting failure analysis (i.e., analyzing the causes of a design failure);¹¹ however, failure is a topic among many other aspects of engineering design or project-based instruction in these studies.^{12, 13, 14} Teachers' approaches and responses to student design failure, as well as student responses to design failure, are sometimes reported within these studies. Student responses to design failure include getting frustrated and giving up, engaging in failure analysis, and seeking to improve.^{10, 15, 16} Teaching approaches in response to student design failure include creating supportive environments where it is okay to fail,¹⁶ or the teacher sharing his own struggles with the challenge and how he learned from "my mistakes."¹⁷

While these studies provide some evidence of how students and teachers have responded to design failure, most have neither focused on failure nor collected a range of student or teacher responses to design failure. Further, these studies have typically examined the design experiences of middle and high-school aged students and their teachers. The present exploratory study aims to address these gaps, focusing on elementary teachers' reported descriptions of how students respond to design failure, as well as teachers' reported responses to students' design failures. It extends and references earlier work on elementary teacher perspectives on failure.⁵

This study operates with the premise that the starting point for a conversation within the engineering education community about how teachers *should* respond to students whose designs have failed is by considering *how* teachers respond to design failure when they teach engineering design challenges to their students. This does not mean to say that their responses are necessarily the best or correct way; yet it does acknowledge teachers' experience and expertise in teaching children. Thus, this study provides an important base of knowledge for the engineering education

community, simultaneously shaping our vision of the ideal ways for elementary teachers to respond to student design failures and our understanding of students' engagement with engineering design in the elementary context. This knowledge base and the visions it clarifies will enable engineering educators (e.g., those in colleges of engineering or education and who often provide professional learning experiences for teachers) to provide meaningful, informed suggestions to teachers about how they can be prepared: 1) for the range of responses students have when their designs fail, and 2) to respond to students whose designs are not successful.

The purpose of this mixed-methods study is to consider how elementary teachers who taught one or two Engineering is Elementary (EiE) units of instruction reported how students responded to design failure – and, in turn, how they themselves responded to students whose designs had failed (see Figure 1). A convergent mixed-methods design, in which quantitative and qualitative data are used in parallel, was employed.¹⁸ Quantitative and qualitative data gathered from post-teaching surveys was used to examine the following as reported by 108 teachers: the frequency of students' design failures, students' responses to design failures, and teachers' responses to student failures. Interviews with a subset of 14 teachers were used to explore student and teacher responses with more depth. This mixed-methods approach provides both a broad perspective on the topic using quantitative data from a large number of participants, and a more complex, qualitative examination of student and teacher responses to design failure as reported by a smaller sample of teachers who participated in interviews.

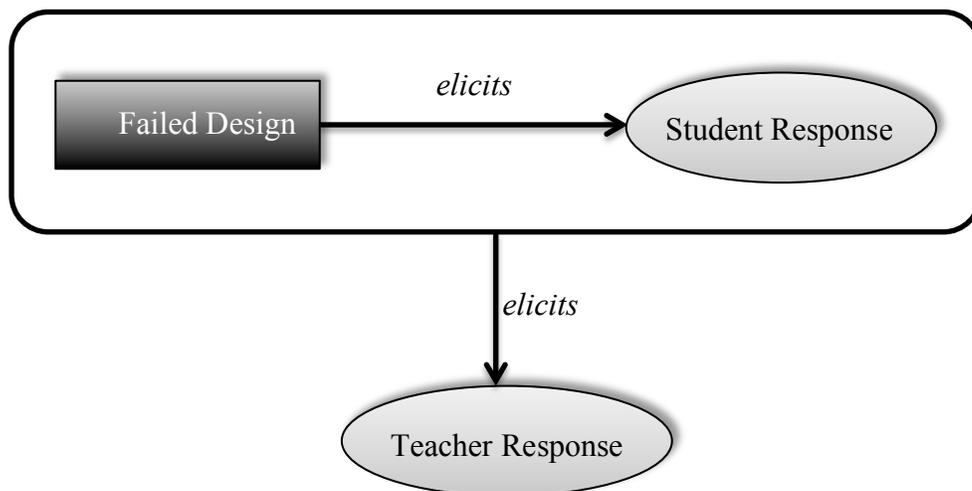


Figure 1. The purpose of the study is to examine *student responses* to design failure, and *teacher responses* to students whose designs have failed, both of which are reported by teachers.

Literature Review

The increasing inclusion of engineering principles in the PreK-12 setting was accelerated with the release of *A Framework for K-12 Science Education: Practices, Crosscutting Concept and Core Ideas* and the subsequent standards document, *The Next Generation Science Standards*.^{1,7,8} Engineering is still, however, a recent and complex challenge for teachers, particularly those at the elementary level, who often lack self confidence and self efficacy with regard to teaching engineering.^{1,2} Teachers' self confidence in a subject is linked to both how

they perceive it and their knowledge of the subject itself.¹⁹ Elementary teachers receive little to no training in engineering in either pre-service preparation or in-service professional development; in fact, they have rarely or only recently been exposed to or know how to teach engineering, and rely on pedagogical strategies they use in other content areas.^{20,21} Self efficacy in engineering education, according to Yoon Yoon and colleagues, is “a teacher’s personal belief in his or her ability to positively affect students’ learning of engineering” and is critical to the subject being taught to students at all.²² Part of teaching engineering design is helping students navigate failure experiences.^{1,2,3,4} However teachers may lack self efficacy in this area given that their teaching and learning experiences related to failure may be negatively associated or may not translate into clear pedagogical strategies.⁵

The challenge of including engineering within the elementary classrooms is further complicated by the dichotomy between how failure has been traditionally perceived within engineering and education.⁵ Within engineering, the engineering design process accounts for the likelihood of failure by its iterative nature; it is presumed that initial attempts to solve a particular problem may fail to meet design criteria or not meet those criteria as well as subsequent designs. Henry Petroski, a frequent writer on engineering failure, reflects on the nature of engineers to continually learn from failure, in effect establishing it as a normal part of engineering design:

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.²³

End point failure, however, is not a desired outcome for an engineer. When such failures occur, analysis of the event is performed to understand heretofore-unknown risks or the impact of unintended usage, or to examine the failure in light of new knowledge or research.²⁴ Engineers persistently engage in what Petroski calls a “thoughtful reappraisal of even centuries-old failure[s] to yield new lessons from old examples.”²⁵ Designing and testing for limits to establish factors of safety at final product stage is an engineering norm. In the field, failure is used as a means to understand materials (or other resources) or design limitations.²⁶

Failure within P12 education literature is largely limited to accountability reporting, e.g.: “failing schools” or schools who do not as a whole achieve proficiency on mandated tests, or “student failure” or a student’s inability to demonstrate cognitive knowledge.²⁷ In both engineering and education, the ramifications of failure can be seen as catastrophic with respect to the damage being done (e.g., to technologies, people, students). Engineers will use the data to plan to avoid such a situation in the future, whereas in education the reaction typically involves some sort of remediation (e.g., employed to impact individual students to be able to demonstrate proficiency in a subject test). In both fields, failure can and does become public fodder.

The introduction of engineering design to education creates the opportunity to address explicitly the idea of failure in the P12 classroom in a way that is not as loaded with negative meaning as it usually is within educational settings.^{28,29} Increasing use of the word failure in P12 literature is exemplified by Moore and colleagues, for example, in their identification of the six characteristics of high quality STEM integration, including providing “opportunities for students to learn from failure and redesign.”³⁰ As a normal part of engineering, we argue that failure – or

perhaps the normalcy of failure – be promoted as an engineering habit of mind for students to practice within P12 engineering education. Engineering habits of mind are engineers’ ways of thinking and doing,³¹ and include “systems thinking ... creativity ... [and] optimism.^{32,i} Including the normalcy of failure – and thus, productive and resilient responses to failure – as another engineering habit of mind seems appropriate given that engineers’ ways of thinking and behaving include ways of thinking and acting about failure. As argued earlier, however, failure in the context of P12 education has not been well studied. This exploratory study begins to address this gap, providing insight into student responses to failure and, in turn, teacher responses to students whose designs have failed.

Study Context & Participants

In this section, we describe the context and participants for this study. We first address how this study is situated within a larger study, the E4 Project, and summarize the participant selection processes for the E4 Project and the present study. Next, we describe the curricular units that are relevant to the present study and part of the E4 Project, and the professional development (PD) that E4 Project teachers received prior to and after the first year of data collection. The section concludes with a discussion of the way in which the curricular materials and PD experiences referenced and addressed design failure.

Participant Selection

This study is part of the E4 Project, which examines the impact of two engineering curricula on students’ learning about engineering and science, as well as their interests in and attitudes towards careers in science and engineering. One of the two curricula is EiE, and is the focus of the present study; the present study does not include data from the other curriculum. The E4 Project is currently in its second of two data collection years, with data pertinent to the present study collected during and after the completion of the first year (2013 - 2014).

E4 Project recruitment began by disseminating project flyers through state, district, and school level channels within the Massachusetts, Maryland and North Carolina regions. Flyers explained the basic E4 Project study requirements, and encouraged eligible teachers to apply to participate. Eligible teachers taught 3rd, 4th, or 5th grade and had not taught the engineering design process in the past, and would teach students during the two data collection years who had not learned engineering units of instruction. See Lottero-Perdue & Parry for further details regarding project requirements.⁵ Over 600 applications were received. A total of 275 3rd, 4th, and 5th grade teachers from 172 schools were selected to participate in the E4 Project.

Once selected, approximately half of the teachers needed to be assigned to teach the EiE curriculum, and half to the comparison curriculum, which unlike EiE, is not commercially available.ⁱⁱ Since in many cases, multiple teachers worked within the same school, schools (not teachers) were randomly selected to teach either the EiE or comparison curriculum. Ultimately, 135 teachers in 90 schools were selected to teach EiE. Demographics of the EiE schools were statistically similar to those schools using the comparison curriculum. EiE school demographics were as follows: 13% urban, 7% town, 38% suburban, and 42% rural; 72% eligible for Title I funding; mean percentage of white students was 61%, with a standard deviation of 27%; 17%

mean for African American students, 21% standard deviation; 14% mean for Hispanic students, 14% standard deviation.

Of the 135 EiE teachers who began the project, 114 completed the first year of data collection. Of the 114, 73 taught the EiE curriculum to only one classroom of students during year 1, while 41 taught the EiE curriculum to two or more classrooms of students. In total, 3620 students learned the EiE curriculum during the first year of the project.

A subset of 26 E4 Project teachers were selected at the beginning of the first year of data collection for close observation to gather qualitative data regarding teacher instruction, teacher fidelity of implementation, student engagement and teacher-student interactions. Their classrooms are “Case Study Sites” where E4 Project team members: video-record classroom activity and student team group dynamics; interview teachers before and after teaching for the first year of instruction, and again after the second year of instruction; and interview student teams. Case Study Site selection is described in detail in Lottero-Perdue and Parry’s examination of teacher perspectives on failure prior to teaching engineering.⁵ During the first year of data collection, one Case Study Site teacher from each region dropped out (e.g., due to medical and other reasons). Thus, a total of 23 E4 Project teachers participated as Case Study Site Teachers. Of these, 16 taught the EiE curriculum.

All 114 EiE teachers who completed the first year of the E4 Project, as well as all 16 EiE Case Study Site Teachers, were considered as possible participants in the present study. Of the 114 EiE teachers, 108 completed Year 1 and participated in the post-Year 1 survey, which provided quantitative and qualitative data for the study (95% response rate). Of the 16 EiE Case Study Site Teachers, 14 participated in post-Year 1 interviews (88% response rate).

Curricular Units

Each E4 Project teacher had an assigned engineering unit to teach, which was based upon the science content s/he reported teaching in their application. For example, if an EiE E4 Project teacher reported on her application that she taught an electricity science unit to her students, then she would be assigned to teach the EiE unit, *An Alarming Idea: Designing Alarm Circuits*.³³ There were a total of eight assigned units in the E4 Project; four of those were EiE units, and four were of the comparison curriculum. Each of the four comparison units was similar to each of the EiE units with regard to the engineering field of focus for the unit. The four EiE assigned units are listed and described in Table 1.

There are common features across all of the EiE units for the E4 Project. Each unit has an associated teacher guide and student workbook. The teacher guides are extensive – approximately 150 pages in length – and include objectives, connections to science content, materials lists, assessments, and lesson plans written in detail. The student workbook contains all student worksheets and reflective journal pages that students use throughout the unit.

Table 1. EiE E4 Project units.^{33,34,35,36,37}

Unit <i>(Unit Abbreviations)</i>	Engineering Field	Background Science Concepts	Engineering Design Challenge
An Alarming Idea: Designing <i>Alarm Circuits</i>	Electrical	Conductors and insulators, circuits, schematic diagrams	Engineer a switch and an alarm circuit
A Stick in the Mud: <i>Evaluating a Landscape</i>	Geo-technical	Earth’s layers, Soil properties, erosion	Determine the best location for a TarPul, a cable bridge that carries cable cars
A Slick Solution: Cleaning an <i>Oil Spill</i>	Environmental	Ecosystems, food webs, water quality testing	Engineer a process to clean up an oil spill
Thinking Inside the Box: Designing <i>Plant Packages</i>	Packaging	Plant parts, plant needs	Engineer a package that can keep a plant healthy for several days

Each unit has the same preparatory lesson in which students come to understand that technologies are objects, processes, or systems that humans create to solve a problem. Additionally, each EiE unit is made of four lessons. In Lesson 1, students read a storybook, which introduces the engineering field and engineering challenge and situates a child protagonist in the problem-solving role of an engineer. In Lesson 2, students engage in an investigation or hands-on activity that presents a broader view of the engineering field than is presented in the storybook. In Lesson 3, students gather data that will inform the engineering design challenge. In Lesson 4, students use the engineering design process (EDP) to engage in the engineering design challenge. The EDP, which is introduced in Lesson 1 and performed in Lesson 4, is described in Table 2. Note that there are two major opportunities for design failure within the EDP within the Create and Improve steps.

Table 2. EiE engineering design process (EDP) steps and descriptions.³⁸

EDP Step	Description of Step <i>with Opportunities for Design Failure Identified</i>
Ask	What is the problem? How have others approached it? What are your constraints?
Imagine	What are some solutions? Brainstorm ideas. Choose the best one.
Plan	Draw a diagram. Make lists of materials you will need.
Create	Follow your plan and create something. Test it out! (<i>Opportunity for Design Failure</i>)
Improve	What works? What doesn't? What could work better? Modify your designs to make it better. Test it out! (<i>Opportunity for Design Failure</i>)

In addition to teaching their assigned unit, prior to the beginning of the first year, E4 Project teachers could apply to teach another unit within their assigned curriculum about bridges

and civil engineering (hereafter, the *Bridges* unit). During the design challenge for this unit, students would engineer a strong and stable bridge using basic knowledge of pushes, pulls, and balanced forces. This unit would precede the teaching of the assigned unit. Approximately 65% of the teachers in each region applied to teach the *Bridges* unit, however, there were only enough resources within the project to support half of the teachers to do so. To determine who would teach the EiE *Bridges* unit, EiE E4 Teachers who expressed an interest in teaching the *Bridges* unit were randomized within each of the three regions. Teachers were accepted to teach the *Bridges* unit in random order; however, once half of the EiE E4 Teachers who were teaching a particular assigned unit (e.g., the *Alarm Circuits* unit) had been selected, that unit was regarded as being “full” and no more teachers teaching that unit in that region would be selected to teach *Bridges*. Ultimately, 56 EiE teachers taught the *Bridges* unit during Year 1.

Caveats about unit effects in the study: Teachers who taught the *Bridges* and assigned units differed from teachers who only taught the assigned unit in two simultaneously occurring ways: 1) they taught *two EiE units* rather than one; and 2) the *Bridges* unit was *different in content* than the assigned units, i.e., addressing a different engineering field and involving a different engineering challenge. This dosage effect makes it impossible for our study to separate the effects of teaching two versus one units and having taught the *Bridges* unit versus not having taught the *Bridges* unit. In addition, this study does not compare the effects of the eight different unit combinations in the study (e.g., two of those being *Alarm Circuits* only and *Bridges* and *Alarm Circuits*). This is due to low numbers of participants teaching each combination.

Professional Development

Prior to the beginning of the first year of teaching, all E4 Project teachers participated in a three-day long PD experience; participation was a project requirement. For each region, EiE teachers received PD on a different three-day period than did comparison curriculum teachers. During the workshops, the same two E4 Project team members across all three regions addressed study requirements and logistics, and taught the teachers three of the five units within their assigned curriculum. The EiE teachers all learned the *Bridges* unit, and then were split into two groups to learn their assigned unit and one additional unit: 1) *Alarm Circuits* and *Evaluating a Landscape*, and 2) *Oil Spill* and *Plant Packages*. This provided teachers with a broader learning experience in engineering education beyond simply learning their assigned unit. For each EiE unit addressed, E4 Project team members guided teachers through the teacher guide and student workbook, closely following the curriculum. In addition, they led discussions regarding how to encourage collaboration and creativity, and how to make connections to science content.

E4 Project teachers were invited to a single day of optional follow-up PD towards the end of the first year of teaching data collection. Roughly two thirds of E4 Teachers attended the follow-up workshops, which had the following goals: 1) to reflect on the first year teaching (e.g., successes and challenges); 2) to review the EDP; 3) to develop and brainstorm, observe (on a video) and discuss effective questioning strategies for use in engineering design challenges; and 4) to reflect on data collection procedures.

Extent to which Failure is Explicitly Addressed within EiE PD Experiences and Units

During the first PD experience prior to Year 1, failure was not addressed as a separate topic; teachers were not told to explicitly discuss failure as a topic as they taught engineering, nor were they told to avoid discussing failure as a topic. The curriculum materials served as guides for when words like fail, failed or failure (hereafter, “fail words”) occurred. Of the *Bridges* and assigned units, the *Bridges* unit used these words much more than others. For example, one example from the *Bridges* unit is as follows:

Spend a few minutes discussing “failure” as a class. Explain to students that they should keep adding weights to the span of their bridge until the center of the span bends below the bottom of the first block on the abutment.³⁹

Table 3 summarizes the number of instances in which the fail words were used in the EiE teacher guides and student workbooks. Note that for all of the teacher guides, two instances included: 1) that a goal of the EiE curriculum is for students to “troubleshoot and learn from failure;”⁴⁰ and 2) a comment that began, “if all else fails ...”⁴¹ which was the only instance of failure word use that was not specifically related to design failure.ⁱⁱⁱ Clearly, the *Bridges* unit had the most mentions of fail words, followed by the *Evaluating a Landscape* unit.

Table 3. Summary of instances in which the fail words are used in the EiE teacher guides and student workbooks for the E4 Project Assigned and *Bridges* units.

Unit	Uses of F-words in	
	In EiE Teacher Guide	In EiE Student Workbook
<i>Alarm Circuits</i>	5	0
<i>Evaluating a Landscape</i>	3	5
<i>Oil Spill</i>	2	0
<i>Plant Packages</i>	2	0
<i>Bridges</i>	30	8

Regardless of whether or not fail words were explicitly used within the units, each unit presents multiple opportunities for designs to fail by not meeting the criteria or constraints of the design challenge. Opportunities for design failure within the EDP occur each time a designed solution is tested, i.e., at the end of the Create and Improve steps (see Table 2). Failure may also occur in other places within the EDP, for example in the planning stage, as students fail to consider criteria or constraints. However, post-testing design failure is the focus of this study.

During follow-up PD, EiE teachers spent time explicitly addressing what to do when designs do not meet stated criteria. As part of this, they watched a video of a teacher, Laura, as she helped students engage in failure analysis and the improvement process.⁴² While Laura did not use fail words in her instruction, a slide used during PD to reflect on the video asked: How does Laura encourage her students to persevere through failure? Later in the follow-up PD, teachers were asked to address multiple questions pertinent to their unit. Three of these questions addressed failure, however; albeit not via use of the word: 1) How did you respond to

students/teams when their first (or second, or third) design was not successful? 2) What did you say? and 3) What did you try not to say?^{iv}

Research Questions & Hypotheses

The present study considers how elementary teachers reported students' responses to design failure and – in turn – teachers' own responses to student design failure during the engineering design process as they reflected upon teaching their assigned EiE unit and, if applicable, the *Bridges* unit. This convergent mixed-methods investigation was guided by: qualitative research questions, which also serve as the study's overarching questions; descriptive quantitative research questions and null hypotheses; and a mixed-methods research question.

Qualitative Research Questions (and overarching questions for the study):

1. How do teachers describe the ways in which students responded to design failures?
2. How do teachers describe the ways that they responded to students whose designs were unsuccessful?
3. To what extent did teachers report using the fail words as compared to euphemisms or alternatives to these words when they responded to students?

Quantitative Descriptive Questions:

1. What percentage of students in teachers' classes, as reported by the teachers, was able to produce a successful design by the end of each unit (*Bridges* and assigned)?
2. Which of 13 possible responses (see Appendix) did teachers report using in response to students whose designs were unsuccessful (i.e., failed the challenge)?

Null Hypotheses:

- H₀₁: There is no difference in teachers' reported use of the 13 different responses to students whose designs were unsuccessful.
- H₀₂: There is no difference in teachers' reported use of responses that include fail words as compared to their reported use of responses that do not include these words.

Mixed Methods Research Question:

In what ways does the qualitative data gathered via interviews extend and elaborate quantitative and qualitative survey findings regarding how teachers respond to students whose designs were unsuccessful or how teachers used fail words?

These questions and hypotheses represent a continuation of a multi-year study in which students' and teachers' responses to and reflections on design failures in the classroom are investigated as part of the aforementioned E4 Project.

Methods

This study has been shaped by both pragmatic and constructivist worldviews. Pragmatism is a “real-world, practice oriented approach.”⁴³ It links thought and action in which “ideas operate as instruments rather than ideals.”⁴⁴ The focus for pragmatism is on the overarching research question(s) and the “use [of] all approaches available to understand the problem.”^{45,46}

These approaches include both quantitative and qualitative methods within research, not strict adherence to one or the other. Pragmatism is a common worldview for mixed methods research, a methodology that began circa 1990 in a variety of social science fields.⁴⁷ In short, the power of mixed methods research is that it draws from the strengths of quantitative and qualitative research, and by attending to both approaches, the weaknesses of each – e.g., lack of generalizability for qualitative research, and lack of depth and complexity for quantitative – are minimized.

Although the study employs a mixed-methods approach, it leans somewhat more heavily on qualitative data gathered within surveys and interviews. A constructivist worldview is used to make sense of these data. Such a worldview supposes that: there exist multiple realities to explore, participants' perspectives provide a foundation on which to build patterns and theories, and researchers are close to the sites of research.⁴⁸ Constructivism guides the qualitative inquiry within our broad pragmatic approach.

A convergent parallel mixed methods design, with emphasis on qualitative methods, (QUAL + quan) has been employed in this study.⁴⁸ In this design, qualitative and quantitative data have been collected within roughly the same timeframe. Quantitative and qualitative data were analyzed separately, and then the analytical results were compared and related to one another, and instances of convergence and divergence are considered in the interpretation of findings.^{47,48} In particular to this study, qualitative data in the form of interviews were collected beginning in January and ending in June of Year 1 (see Figure 2). Early interviews, as well as findings from a prior study,⁵ contributed to the development of the Post-Year 1 Survey, collected in the latter half of June in Year 1. Surveys were completed after Post-Year 1 PD had occurred. Survey questions were designed to gather a mix of qualitative and quantitative data



Figure 2. Data collection during/after Year 1 within the convergent mixed methods design.

The purpose of the survey was to explore the widest range possible of teacher-reported teacher and student responses to student design failure within the EiE E4 Teacher population. This was done to make inferences about: 1) the frequency of design failure for 3rd, 4th and 5th grade students learning an EiE unit for the first time; and 2) how other 3rd, 4th or 5th grade teachers and their students may respond to student design failure whilst teaching an EiE unit for the first time. Given that this was a nonrandom sample, we recognize that this sample of EiE E4 Teachers (N=108) is not entirely reflective of the population of all 3rd, 4th or 5th grade teachers.

While surveys provide an expedient means of collecting data from many participants, the brief responses collected by survey data may not necessarily reveal the complexities and richness that in-depth interviews can provide. The purpose of interviewing Case Study Site teachers (N=14) was to investigate more detailed accounts of teachers' reports of student and teacher responses to design failure. In future work, these interview data will be compared to video and audio data collected during instruction (see more about this in the final section of this paper).

Survey Data Collection

As depicted in Figure 1, the post-Year 1 survey was cross-sectional, taken once in the latter half of June 2014 following Year 1 of data collection. During this time all E4 Teachers received a 21-item survey via an online survey program, Formstack, to gather information regarding teachers' perspectives and experiences from the first year of the project. Several email reminders encouraged teachers to complete the survey throughout the two-week period. Survey questions included open and closed-ended questions; several of the latter type had multiple parts (e.g., indicating agreement/disagreement with a range of related statements). Six of the 21 items on the survey, three quantitative and three qualitative, were relevant to the present study. These questions, which explored the extent to which students' designs were successful, how students responded to design failure, and how teachers responded to students whose designs were unsuccessful, are shown in Appendix A-1.

Survey Validity and Reliability

All six 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; see discussion, below, for the co-authors' alternative to inter-coder agreement for qualitative items. We argue, however, that the questions were written well enough to be clear, and that it was unlikely that teachers responded with random answers due to a lack of clarity about what questions were asking. The questions focused on pedagogical behaviors they themselves had engaged in or student behaviors that they had observed.

Although we have not conducted strict validity procedures, we suggest that the survey questions have a high degree of content validity, and also have 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, studying, and working with elementary teachers as they learn to teach EiE units of instruction. The 13 possible teacher responses to student failure were included because they: included statements about analyzing failure and improving after failure that both did and did not include fail words; and represented themes about elementary teachers' perspectives on failure learned in earlier E4 Project work.⁵ With respect to construct validity, the quantitative and qualitative survey items were very directly related to the construct we sought to measure. For example, teachers were asked to provide "examples of things you would say to a team that produced an unsuccessful design," and the construct we sought to measure was: how teachers reported students and their own responses to students' failed designs.^v

Survey Data Analysis – Quantitative & Qualitative Methods

Descriptive analysis of quantitative data involved the calculation of percentage response rates by teacher survey respondents. To describe the student design success rate, which implied rates of design failure, we determined the percentage of 108 teachers who reported particular frequencies – ranging from less than 10% to 100% in 10% increments – of their students who achieved design success by the end of the assigned unit. This was repeated for the *Bridges* unit for the 56 teachers who taught that unit. The percentage of teachers who responded affirmatively to using each of the 13 aforementioned statements and questions was also calculated.

Inferential analysis of quantitative survey data began with a Kolmogorov-Smirnov test to determine if the data were not normal. Since data were indeed not normal, nonparametric analytical methods were used. Wilcoxon Signed Ranks tests were used to determine the significance of difference of response frequencies, for example when comparing the frequency of affirmative responses for one versus any other of the 13 statements or questions in response to students whose designs were unsuccessful. Two-tailed significance at levels less than or equal to 0.05, as well as effect sizes, were reported.

Qualitative survey data were analyzed using an iterative search for common statements, ideas, or approaches (codes) to inform the major themes of the study.⁴⁷ Two sets of data were analyzed in this way: 1) other teacher responses to students' design failure (N=35), and 2) student responses to design failure with respect to the assigned unit (N=107) and *Bridges* unit (N=56). In both cases, co-authors independently read and re-read and coded the data according to a set of codes each had developed. The co-authors then discussed and came to consensus on a set of common codes, and, working together, re-coded each submission according to common codes. One exception to this process was that three codes, describing the nature of the entire response submitted by each survey respondent, were predetermined for the student response data: overall positive response, overall negative response, and overall mixed response. Another exception is that the first author analyzed both sets of data for the explicit use of the fail words. Ultimately, 11 codes described the other teacher responses data; 21 codes described teacher responses data.

Interview Data Collection

Case Study Site teachers were asked to participate in a post-teaching interview sometime in the month following the completion of one (for the assigned unit only teachers) or both (for the *Bridges* and assigned unit teachers) units. Of the 16 Case Study Site teachers who taught EiE curriculum, 14 were able to arrange for these post-teaching interviews. Interviews were semi-structured in format,⁴⁹ and lasted between 20 minutes and one hour. A synopsis of the interview protocol, which probed teachers for how students responded to design failure and how the teachers, in turn, responded to those students, can be found in Appendix A-2. Seven of the 14 interviews were audio-recorded and transcribed; for the other seven an E4 Project staff member took extensive notes with verbatim passages during the course of the interview. Four interviews were conducted in person, and ten took place over the phone.

Interview Data Analysis

Pseudonyms were assigned to all 14 interviewees. The 14 interview notes/transcripts were imported into HyperResearch™ qualitative analysis software. Qualitative analysis of the interview data involved an iterative search for student responses to failure, teacher responses to students whose designs had failed, fail word use, and factors that might influence responses and word use.⁴⁷ Throughout this process, codes were identified, refined, and at times removed or renamed. The co-authors began this process by independently coding the data, and sharing and discussing initial patterns and codes. The first author then generated a new code list, and the co-authors then re-coded the data independently, shared these codes, and came to consensus on a near-final set of codes and corresponding text within the interviews (some codes were further sub-coded by the first author). Ultimately, 48 codes described 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 and student responses, 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.

Researchers' Roles

Both the first and second author are co-principal investigators on the E4 Project, and are leaders for the project in their respective states. They have collected extensive video data within Case Study Site classrooms within their regions, conducted Pre- and Post-Year 1 interviews with teachers in their regions, and were present for and supported the initial PD in the summer of Year 1 and provided the Post-Year 1 PD in their regions. They are immersed in the project, and as such, are able to interpret survey responses in the context of the study, and ask relevant follow-up questions during interviews. These are strengths. However, they may also be regarded as weakness and a potential source of bias. For example, although we have attempted to capture a broad range of teachers' reported responses to failure, we may be inclined to see teacher responses in positive, rather than critical, ways.

Mixed Methods Analysis

In the section that follows, after describing the survey findings regarding student design success, we present the survey findings regarding student responses to failure followed by how the interview data regarding student responses to failure compare and contrast to these responses. We use a similar format for presenting teacher response findings. This attempts to address the aforementioned mixed methods research question, reduce redundancy, and highlight the way in which interview data enhances and elaborates survey findings.

Findings

Student Design Success and Failure – Survey Findings

Teachers' estimates regarding the percentage of students who achieved design success for the *Bridges* and assigned units indicate that while many students achieved design success, many

also experienced design failure. In other words, failure was not an unusual experience. Table 4 summarizes these data. For example, over three quarters of the teachers teaching their assigned unit (N=107) shared that between 50% and 90% of their students had a successful design in the assigned unit; thus, between 10% and 50% of their students did not achieve design success (i.e., had failed designs). Note that while 12% or 13% of teachers reported that 100% of their students achieved design success for either the assigned or *Bridges* unit, this does not imply that none of these students had a failed design. Rather, it implies that all students achieved design success at some point within the engineering design process – a process that includes at least two designs per student team.

Table 4. Teachers’ estimates regarding the percentage of students who achieved design success for the assigned and *Bridges* units.

Reported Success Levels	Percentage of Teachers Who Reported this Success Level	
	For the Assigned Unit (N=107*)	For the <i>Bridges</i> Unit (N=56)
All students had a successful design at some point in the engineering design process	12%	13%
Between 50% and 90% of students had a successful design	77%	64%
Between 0% and 40% of students had a successful design	11%	23%

* Here and elsewhere, the number of assigned unit teachers is 107 since one of the 108 respondents taught the *Bridges* unit, but not her assigned unit.

Student Responses to Failure – Survey Findings

Teachers reported the way in which students responded to design failure for the assigned unit (N=107) and *Bridges* unit (N=56), respectively. These student responses were placed into four codes with respect to the overall nature of each teacher’s submission:

1. An *overall positive* response: All comments within a teacher’s submission suggested resilient, productive responses to failure (e.g., trying again, figuring out what went wrong) and positive emotions (e.g., excitement). Example: “They collaborated with other groups and tried again. They loved doing it and were determined to be successful!”
2. An *overall negative* response: All comments within a teacher’s submission suggested non-resilient responses to failure (e.g., giving up, blaming others) or negative emotions (e.g., frustration). Example: “There was definite frustration. Many would express with their arms, or some with just words.”
3. An *overall mixed* response: Some aspects of the submission described resilient responses, while others described non-resilient responses. Example: “Some students were determined to understand why it didn’t work and make changes to fix it. Others became frustrated and lacked further interest.”
4. An *overall unclear* response: This was an off-topic submission that neither expressed resilient/non-resilient behaviors nor positive/negative emotions.

Figure 3 shows that for both units, most submissions (80% for the assigned units and 72% for the *Bridges* unit) include student responses that were either entirely or partially positive/resilient.

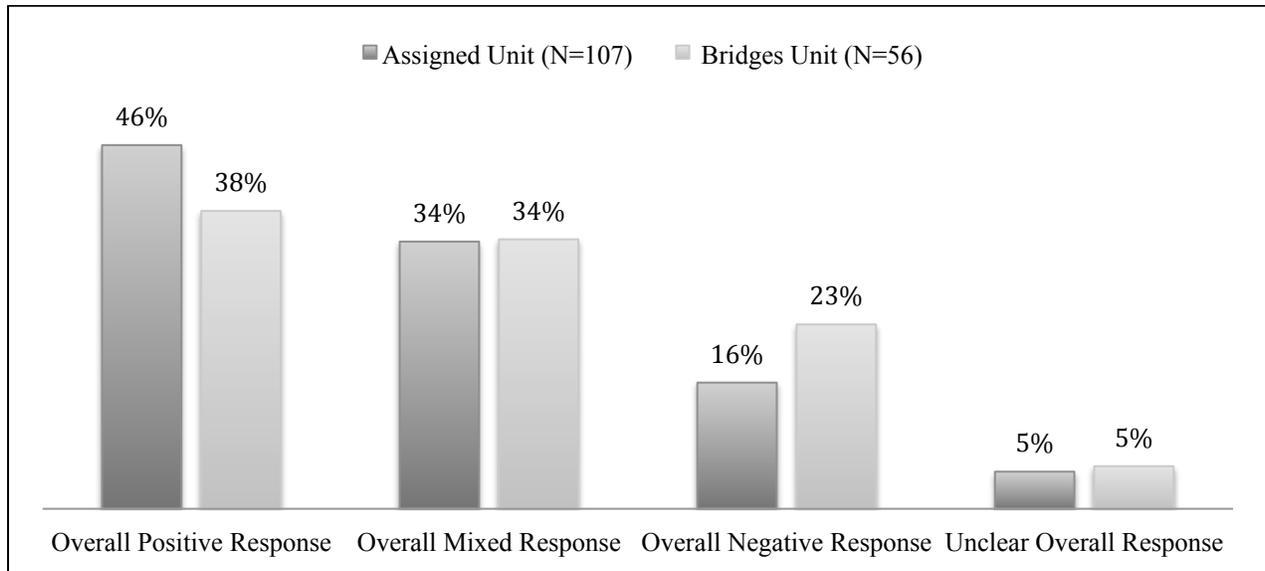


Figure 3. The overall positive/resilient, negative/non-resilient, mixed or unclear nature of teachers' submission of students' responses to design failure.

A total of 13 teachers in the study (12% of 108) submitted 16 student responses that contained fail words; 3 teachers submitted student responses containing these words for both their assigned and the *Bridges* unit. More teachers who taught the *Bridges* unit submitted student responses containing the fail words (21% of 56) than did those who taught the assigned unit only (4% of 107). Over half (54%) of the 13 teachers referenced *design failure* or that the design failed within the student response. For example, one teacher reflected on the Alarms Circuit assigned unit, offering: "Students were excited about the switches but seemed disappointed when the design failed." Nearly one quarter (23%) of the teachers focused on *student failure* rather than on design failure. One teacher mentioned students in both units who "failed" due to a lack of planning. Another offered that her students "did not do well with the failure of their ideas." Another shared that in both the assigned and *Bridges* units, her students had no feeling of defeat or failure. Finally, some teachers (31%) *used failure in a broad way*, not indicating if the failure was with respect to a failed design or student failure, e.g.: "They were bummed out but handled the failure fine because they knew they would have a chance to improve their designs."

Within each teacher's submission about how students responded to design failure was one or more positive/resilient or negative/non-resilient student responses. Codes that represented the positive/resilient student responses reported by 5% or more of assigned unit (N=107) or *Bridges* (N=56) teachers are shown in Table 5. Table 6 shows the negative/non-resilient responses. The percentage of teacher response rates for each code was similar for the assigned and *Bridges* unit.

Table 5. Positive/resilient student responses reported by 5% or more of assigned unit or *Bridges* unit teachers.

Code	Example	Percentage of Teacher Responses	
		Assigned Unit (N=107)	<i>Bridges</i> Unit (N=56)
Wanted to (or did) try again or redesign	“... some were motivated to keep trying ...”	36%	38%
Focused on improvement	“The group that was unsuccessful immediately began talking about how to improve their design.”	34%	32%
Expressed a positive emotion	“They yelled in excitement (Oh, noo... AAHHH... etc.) and then tried again. They had a great time.”	17%	16%
Engaged in failure analysis	“They would discuss why it did not meet the criteria like the others ...”	15%	13%
Sought help from peers or looked at what others had done	“... Some students went to other groups to see what they did and wanted to borrow ideas ...”	13%	9%
Worked effectively as a team	“... Continue[d] to keep working with team members.”	9%	2%

There were more responses coded as students expressing negative emotions than positive emotions (e.g., 32% versus 17% of assigned unit teachers); the most frequently used word to describe negative emotions was some variant of the word “frustration.” Although negative emotions were represented more frequently across the teachers’ responses, teachers described more resilient responses to failure (e.g., trying again, focusing on improvement, engaging in failure analysis) than non-resilient responses (e.g., giving up, making quick changes rather than carefully planning).

Team dynamics were mentioned by 13% of assigned unit teachers and 7% of *Bridges* unit teachers. Some descriptions of team dynamics were clearly positive, e.g.: working together, working cooperatively (see Table 5). Others were clearly negative, e.g.: blaming, difficulty sharing ideas (see Table 6). However, other descriptions were difficult to code as being positive or negative. For example, some teachers described students as arguing with one another. While this may be problematic, it may also be evidence that students are engaged in the practice of argumentation that engineers would use as they determine how to proceed in the design process.

In addition to the codes listed in Tables 5 and 6, other codes emerged from the analysis of the teachers’ responses regarding student responses to design failure, albeit with a frequency of less than 5% for either the assigned unit or *Bridges* unit teacher groups. Some teachers (3% of assigned unit, 2% of *Bridges* unit teachers) reported that students used the EDP to guide their next steps after a failed design. Teachers (2%, 0%) also shared that students referenced or used background information from earlier in the EiE unit or in the associated science unit as they

considered their failed design and what to do next. In contrast, some teachers reported that students ignored this background information (3%, 0%). Teachers (2%, 4%) mentioned that students asked for help when their designs failed; other teachers mentioned that students wanted teachers to give them the right answer (1%, 2%). While some teachers (13%, 9%) reported that students benefited from observing the work of other groups, others reported that students felt bad when other groups were successful (2%, 2%).

Table 6. Negative/non-resilient student responses reported by 5% or more of assigned unit or *Bridges* unit teachers.

Code	Example Excerpt from Submission	Percentage of Teacher Responses	
		Assigned Unit (N=107)	<i>Bridges</i> Unit (N=56)
Expressed a negative emotion	“Some cried or got frustrated at first ...”	32%	41%
Gave up or lost interest	“Some of my students wanted to give up and say it could not be done ...”	9%	14%
Quickly modified design without planning	“... It was difficult for them to step aside and "plan" first, they wanted to adjust it right then ...”	6%	7%
Engaged in negative team dynamics	“They tried to blame group members ...”	4%	5%
Stayed with original failed design	“... a couple of them just stuck with their original design even if it didn't work ...”	2%	5%
Saw the task as being impossible or too difficult	“... Some assumed that there was no way to make the design successful ...”	5%	2%

Student Responses to Failure – Interview Findings

During interviews, teachers were asked how their students responded to design failures, be those failures of the first or second designs within the EDP. They also described students’ responses to design failures at other points in the interview. Consistent with the survey data, interviewed teachers (N=14) described resilient, positive and productive student responses to failure. Teachers reported that students: expressed positive emotions (mentioned by 86% of interviewed teachers^{vi}); focused on how to fix or improve their designs (79%); engaged in failure analysis (50%); prepared themselves to try again (36%); engaged in positive team dynamics (36%); and benefitted by looking at what other teams had done (29%). Also consistent with survey findings, teachers described the following non-resilient, negative or unproductive responses to failure where students: expressed negative emotions (71%); engaged in negative team dynamics (57%); gave up or stalled and did not know what to do next (50%); made rapid, rather than thoughtful, changes to their designs (29%); and wanted to stay with their initial

designs, despite evidence that those designs failed (14%). These student responses coded within interview data all mirror codes previously shown in the survey responses.

In addition to these responses, interview data added to survey findings with regard to teachers' perceptions of student responses to design failure. In particular, seven student response themes emerged from interview analysis. Teachers reported that students responded by: identifying as failures (or not), avoiding failure, using background information, cheating, competing, not caring, and responding as they do in other subjects.

Identifying as Failures. Teachers described student responses that indicated not just negative or positive emotions of students, but also negative (21%) or positive (7%) identities that students may have taken on in response to failure. For example, Sean,^{vii} in describing the range of responses to design failure in his class, said: "... others thought of themselves and their design as a failure." In this way, Sean's students, according to Sean, took on failure identities. In contrast, Jessica described how her students did *not* take on such identities:

I mean, kids were disappointed but they didn't take it to heart and think, "Oh, I'm terrible." They tried to think, "How can we make it better?", which is, I think, to me, that's one of the biggest things you get out of engineering design process. A failure isn't really a failure. (Jessica)

A way to interpret her final statement may be as follows (emphasis added): "A [*design*] failure isn't really a [*personal*] failure."

Avoiding Failure. In two cases, teachers alluded to occasions in which students preemptively avoid failure – thus responding to the potential of failure – by ignoring constraints or criteria. Students in Diane's class learning the *Oil Spills* unit took more than the allowable number of scoops of oil using a spoon during the oil spill removal process that they designed. About this, Diane shared, "They kept scooping and scooping. Of course, you know, you can scoop it up. I think they all fell in love with the success." Similarly, Jessica questioned the students' self assessment of their plant packages in the *Plant Packaging* unit: "They evaluate themselves, so how accurate those evaluations are [is questionable], because that one team yesterday ... gave themselves a perfect score [for communication], but there was no communication evident." Both Diane and Jessica suggested that it was easier to avoid failure in the *Oil Spills* and *Plant Packages* units. Diane offered that the *Bridges* unit had very "defined criteria" to elucidate success or failure as compared to the *Oil Spills* unit, and according to Jessica, "... with the bridge one, the evaluations were very quantitative and with the plant one, it was more qualitative." Whether a few more scoops or an elevated score, students intentional or unintentional ignoring of constraints or criteria suggested a desire to avoid failure.

Using Background Information. Student productive use of background information to drive the improvement process in response to a failed design was not mentioned extensively within survey data (2% of 107 assigned unit teachers mentioned this). It was also not mentioned frequently within interview data as an initial student response – without teacher prompting – to design failure. However, Joy described a case in which a group of girls in her class created a bridge that failed due to its flimsy structure; the girls had used flat pieces of paper to span the

width of the bridge, and the bridge failed quickly under very low weight. The team, led by one student in particular and without prompting by Joy, decided to combine “what worked from ... the different types of bridges [we had studied] ... into one bridge.” Joy shared, “at that point, they went back to the knowledge we had shared about the different types of bridges and ... combine those ideas into one that was successful.”

Observing Others' Designs and/as Cheating. In both interview and survey data, teachers reported that students whose designs had failed benefitted from observing the work of other teams. This gave students with failed designs greater insights into why their design did not work (failure analysis), and ideas about how to improve. This response to failure was largely conceptualized as a positive and productive response to failure (by 13% of 107 assigned unit teachers on the survey, and 29% of 14 interviewees). However, one teacher, Diane, described this as “cheating.” She explained: “For the bridge design, they walked around. Anybody that was having any marginal success, they’d be like, okay, we’re going to copy off of them.” While Diane captured this as a cheating incident, other teachers may have conceptualized it as a smart way to respond to design failure and determine a way to improve. This illustrates a dichotomy between engineering and education. In engineering, improvements are often based on existing entities, and sometimes, new technologies result. Intellectual property is documented and recognized through the patent process. In the P12 educational system, however, using another’s work has long been considered cheating and is negatively viewed. This difference highlights the gap between the collaborative practice of engineers and the individual academic achievement measured in P12 education.

Competing. Related to observing the work of others in the class, Diane, Joy and Crystal were concerned that students were comparing themselves to other teams as if in competition with those teams. This was similar to the survey response in which a small number of teachers (2% of 107 assigned unit teachers) reported that students felt bad when other groups were successful. Diane described her affluent student population as coming from a competitive environment, and explained that the aforementioned multi-scooping of the spoon to clean the oil spill was a result of this competition. Joy said that during her *Evaluating a Landscape* unit, as compared to her *Bridges* unit, students “were more accepting of the fact that ... just because my design didn’t work out this final round doesn’t mean that I can’t make improvements and doesn’t mean that I’m trying to compete with other groups.”

Not Caring. Two teachers suggested that some students did not care that their designs failed. This is somewhat different than teachers’ aforementioned survey (9% of 107 assigned unit teachers) and interview responses (50% of 14 interviewees) about students giving up; giving up carries with it an implication that one cares or may have cared, but cannot or will not persevere. Janet explained: “I noticed that at first when their designs didn’t work, they were just like ‘oh well.’ And then later I saw them adapt and learn to work through their design failure.” More directly, Anna described “kids who didn’t really care ... [who] would just kind of sit back.”

Responding as They Do in Other Subjects. One teacher, Cheryl, commented in her interview that her students’ responses to design failure were consistent with the way that those students behave in other subject areas. She explained:

Most of the kids that reacted in the way that they did – I could see that carrying over into their other work. The way that they plowed through or needed more scaffolding, or preferred to work with a partner or work with me – I could see how that is pretty much typical of how they navigate through the classroom daily, for the most part. (Cheryl)

In this way, Cheryl was not surprised by her students' responses to design failure.

Only one teacher mentioned student responses to failure that included fail words. Tammy shared, "Sometimes the kids would say 'that's a fail' or 'that's an epic fail' and it was hard for me to get over this word being used in a non-negative context." The implication here is that students labeled the failure, but did so perhaps light-heartedly and in a matter-of-fact way, unlike the teacher, who admitted her own perception of failure is negative.

Teachers' Responses to Students Whose Designs were Unsuccessful – Survey Findings

When given the 13 possible responses to students whose designs were unsuccessful on the survey, most teachers (N=108; 82%) selected "Why do you think your design didn't work?" (Figure 4). This question was intended to engage students in failure analysis, albeit without use

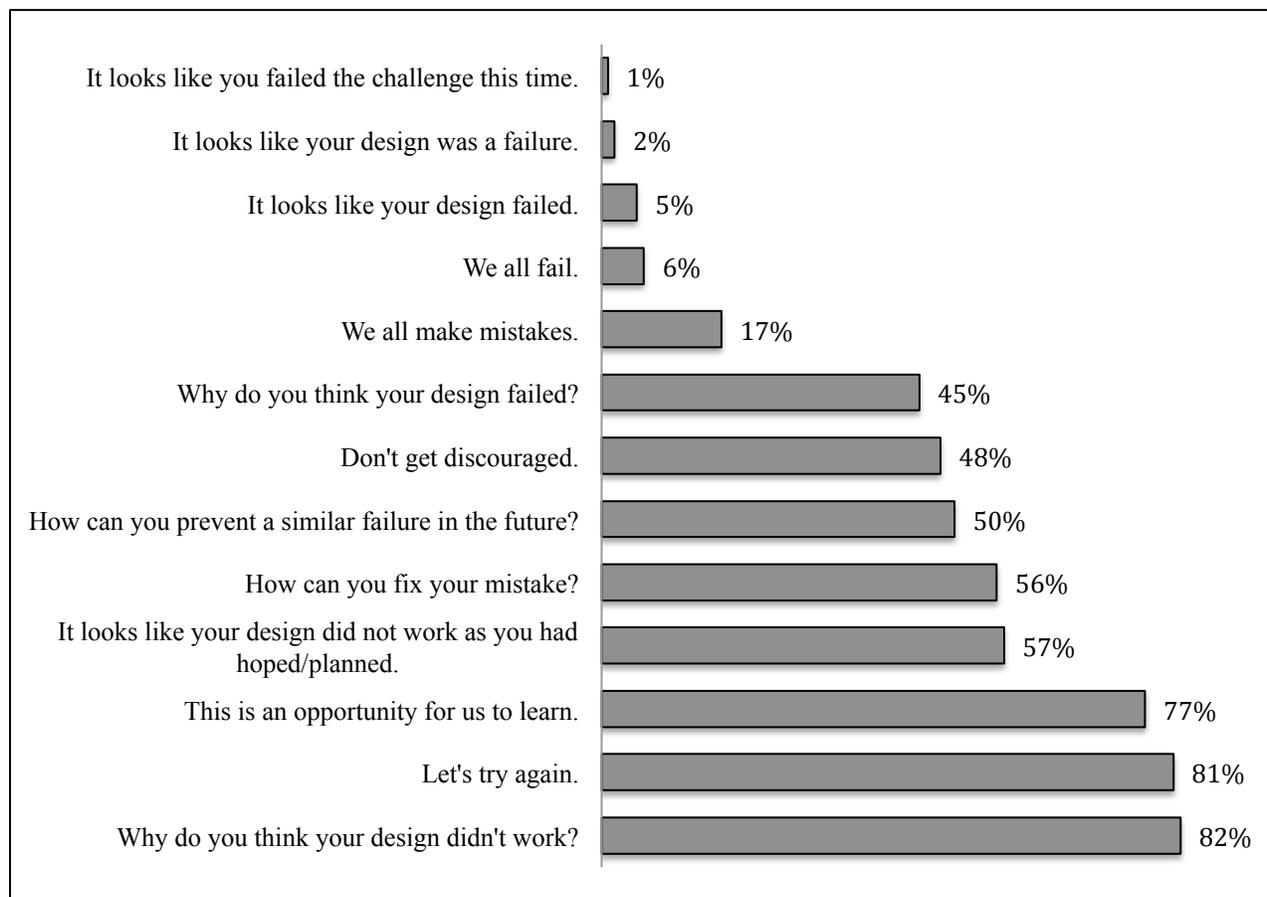


Figure 4. Percentage of teachers (N=108) who reported using certain responses to students whose designs were unsuccessful.

of the word, failure. “Let’s try again,” encouraging students to move into the improvement phase, was another popular response (81%). Positioning the experience as a learning opportunity was selected by 77% of teachers. In contrast, the lowest percentages of teachers (5% or fewer) reported using responses such as “It looks like you failed the challenge this time,” “It looks like your design was a failure,” or “It looks like your design failed.” The three least frequently selected responses used the words failure or failed, while the three most frequently selected responses did not use these words.

Clearly, the data in Figure 4 suggest that there are differences in teachers’ reported use of the 13 responses to students whose designs were unsuccessful. The Wilcoxon Signed Ranks Test was used to determine if these differences were significant; indeed there were many significant differences, providing ample evidence to reject H_{01} (i.e., There is no difference in teachers’ reported use of the 13 different responses to students whose designs were unsuccessful.).^{viii}

Table 7 organizes the responses into four groups. Within each group where there are multiple responses (A, B, and D), the teachers’ reported use of those responses is not significantly different ($p > 0.05$). In effect, teachers reported responding to students whose designs were unsuccessful with “Why do you think your design didn’t work?” about as much as they responded with “Let’s try again” or “This is an opportunity for us to learn;” teachers’ reported use of these responses was similar. Responses within any group *are*, however, significantly different from all other responses outside of the group. Thus, teachers’ use of responses to students whose designs were unsuccessful followed the pattern shown in Figure 5.

Table 7. Groups of responses in which percentages of teachers (N=108) reporting responses within each group are statistically similar (i.e., p-value within each group is greater than 0.05).

Group	Responses	% Teachers Reporting this Response
Group A	Why do you think your design didn't work?	82%
	Let's try again.	81%
	This is an opportunity for us to learn.	77%
Group B	It looks like your design did not work as you had hoped/planned.	57%
	How can you fix your mistake?	56%
	How can you prevent a similar failure in the future?	50%
	Don't get discouraged.	48%
	Why do you think your design failed?	45%
“Group” C	We all make mistakes.	17%
Group D	We all fail.	6%
	It looks like your design failed.	5%
	It looks like your design was a failure.	2%
	It looks like you failed the challenge this time.	1%

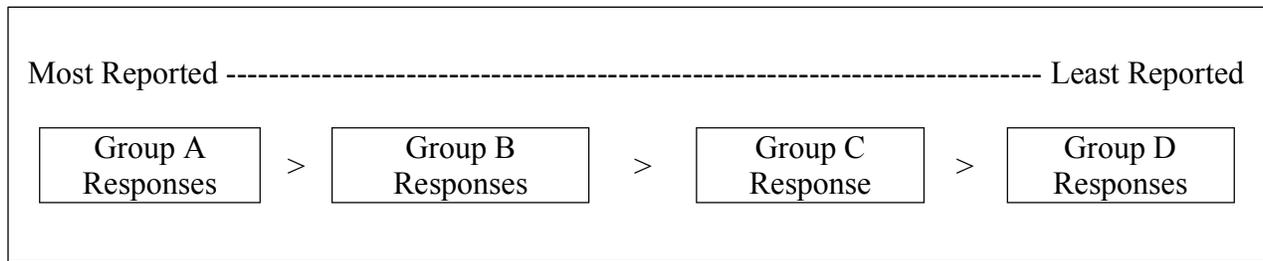


Figure 5. Significant differences (denoted as >) between groups of responses that teachers reported using in response to students whose designs were unsuccessful.

Particularly interesting are comparisons across responses that are similar, yet distinguishable via one of three characteristics:

- Fail word use: The use of fail words versus using a euphemism or alternative word is used.
- Judgment versus action: A focus on judgment about the status of the design (as having failed) or on asking students to engage in failure analysis or improvement.
- Object of failure: Emphasis on a failed design versus you (i.e., the student) failing.

The results of this analysis, which utilized the Wilcoxon Signed Ranks Test, are in Table 8. These results suggest that teachers may be less likely to respond to students using fail words, and more likely to use responses that use euphemisms or alternatives (e.g., “did not work” or “mistake”). This is supported by three of the four pairs of responses that explored the fail word use characteristic, H_{02} (i.e., There is no difference in teachers’ reported use of responses that include fail words as compared to their reported use of responses that do not include these words.).

Further, teachers may be less inclined to use judgment statements and more inclined to provide statements to encourage students to act by either engaging in failure analysis (even if the word, failure, is not used) or by considering how they will improve in subsequent designs. Finally, albeit with a small effect size, teachers may be more inclined to associate the failure with the designs than with the students.

Also on the post-Year 1 survey, teachers were asked if there were examples of “things you would say to team that produced an unsuccessful design” that were not included in the 13 aforementioned responses to student failure. One third of the 108 survey respondents provided examples, which we call “other teacher responses.” Of these, only two (2% of survey respondents) used the words failed or failure; no one used the word, fail. In one example, a teacher shared that s/he would ask: “How can we learn from failure?” Another teacher encouraged failure analysis by asking: “What did you notice when it failed?” Two other teacher responses specifically avoided words like failed and failure. One stated that s/he would not use the word failure, and the other suggested: “just because it didn’t work, it doesn’t mean that you failed.” Nearly one third of the other teacher responses (and 10% of all survey respondents) used euphemisms like “didn’t work” or “not as successful as you’d hoped” in place of instances where words like failed and failure could have been used.

Table 8. Analysis of significance of difference between responses within response pairs that differentiated according to one of three characteristics.

Characteristic	Response Pair	% Teachers Selecting this Response (N=108)	Wilcoxon Signed Ranks Test (p, r)*
Fail word use	It looks like your design was a <i>failure</i> .** It looks like your design <i>did not work as you had hoped/planned</i> .	2% 57%	p = 0.000 r = -0.74
	Why do you think your design <i>failed</i> ? Why do you think your design <i>didn't work</i> ?	45% 82%	p = 0.000 r = -0.52
	We all <i>fail</i> . We all <i>make mistakes</i> .	6% 17%	p = 0.002 r = -0.30
	How can you prevent a similar <i>failure</i> in the future? How can you fix your <i>mistake</i> ?	50% 56%	Not significant
Judgment versus action	<i>It looks like</i> your design was a failure. <i>How can you</i> prevent a similar failure in the future?	2% 50%	p = 0.000 r = -0.68
	<i>It looks like</i> your design failed. <i>Why do you</i> think your design failed?	5% 45%	p = 0.000 r = -0.64
Object of failure	It looks like <i>your design</i> failed. It looks like <i>you</i> failed the challenge this time.	5% 1%	p = 0.046 r = -0.19

* P values are shown for two-tailed significance values less than or equal to 0.05; r is effect size.

** Similar results (p=0.000; r=-0.70) when “It looks like your design was a failure” is replaced with the response “It looks like your design failed.”

Four codes arose from analysis of the other teacher responses, shown in Table 9, which were present in 20% or more of the other teacher responses and 5% or more of the 108 survey respondents. The most frequent response to students whose designs failed was to pose a question to them (63% of other teacher responses). These questions often came in the form of encouragement by the teacher for the students to consider how to improve their design (46%) and/or to engage in failure analysis of their design (46%). Also, teachers reported that they offered general encouragement to students (23%).

Other codes emerged, but represented smaller percentages of teacher responses (<20% of those who responded to the ‘other teacher responses’ question or <5% of survey respondents). These codes included encouraging students to work more effectively in their teams (11% of other teacher responses) and to use the EDP to guide next steps (11%). Also, teachers offered perspective to students whose designs had failed by making connections to the real world or to

Table 9. Teachers’ other responses to students whose designs were unsuccessful represented in >20% of other responses (N=35) and >5% of all survey respondents (N=108).

Code	Example	% Other Teacher Responses (N=35)	% Survey Respondents (N=108)
Asking students questions	“What advice would you give to another 4 th grade civil engineer who may be attempting this for the first time?”	63%	20%
Encouraging students to consider how they can improve	“What could you do to improve your design?”	46%	15%
Encouraging students to engage in failure analysis	“What did you notice when it failed?”	46%	15%
Offering general encouragement	“Good try.”	23%	7%

real engineers (9%). For example, one teacher offered, “we had a lot of discussions about what would happen in the real world with their prototypes,” and another said that she asked students if they thought that engineers were successful with their first designs. Finally, two teachers (6%) encouraged students to observe others’ designs, one offering: “Let’s take a look at another groups’ bridge design that is sturdy and stable, and see how they compare.” Only one teacher response involved a statement that included a judgment about the success or failure of a design, and this response – “Yea! It didn’t work! Now what?” – was also encouraging in nature.

Teachers’ Responses to Students Whose Designs were Unsuccessful – Interview Findings

As with the student response data, much of the interview data regarding teacher responses to students whose designs failed mirrored aforementioned survey findings. Supporting the ‘teachers’ other responses’ survey findings in Table 9, interviewees (N=14): asked questions (57%), encouraged students to improve their designs (50%), encouraged students to engage in failure analysis (36%), and offered students general encouragement (36%). In addition, and building upon less-often cited responses to student failure within the survey, interviewees: referenced real-world technologies (e.g., bridges) and engineers to help students realize that failure is normal, to engage in failure analysis, and to move towards an improved design (50%); encouraged students to work more effectively in their teams (43%); encouraged students to observe other groups’ designs (29%); and suggested that students use the EDP to guide next steps after design failure (14%).

Although there was much in common between survey and interview findings, interviews provided different perspectives and unique insights regarding teacher responses to student failure beyond the survey findings. Topics that highlight these perspectives and insights addressed in this section are as follows: using fail words; using euphemisms of and alternatives to these

words; encouraging students to use background information; withholding judgment about design failure or success; providing direct advice and guidance; not intervening; and not needing to encourage.

Using Fail Words. In contrast to survey findings that suggested that teachers tended not to choose statements that used fail words (from 13 possible responses) and tended not to offer other responses to student failure that contained these words, a large percentage (86%) of interviewees responded affirmatively when asked directly if they used fail words when teaching E4 Project units. Only 14% of interviewees stated that they did not use these words. Of the 12 interviewees who reported using fail words, two offered somewhat general and hesitant statements that included the word “probably.” For example, Bernadette responded: “I probably did. I probably said, ‘if it fails we can try again, we can improve on it.’” With one exception, others who reported using fail words stated that they did so a few times, and largely in reference to design failure criteria within the *Bridges* (6 interviewees), *Evaluating a Landscape* (1), or *Alarm Circuits* (1) units; no teachers described using the word, failure, within the *Oil Spills* or *Plant Packaging* units. Tammy, for example, answered:

Yes. With the bridges, when they collapsed, we called it failure. And with their alarm circuits designs didn’t work, I tried to use the word failure. I tried to convey that failure doesn’t mean ‘done and over’ just that their first design didn’t work. (Tammy)

Janet was the most emphatic of all interviewees in her response to this question about fail/failed/failure word use. When asked about this use, she offered:

Absolutely. I was using it in the context of: ‘What was the failure point of your bridge? How could you correct the failure?’ [We were] looking at failure points and using it often to describe when their design needed improvement. (Janet)

Even prior to responding to the direct question in the interview protocol about fail word use, Janet described her responses to students in this way: “We had conversations about how your response to a problem really either facilitates success for will lead to repeated failure.”

Using Euphemisms. Survey findings also suggested that teachers may prefer to use euphemisms or alternatives to the fail words rather than those words themselves. Nearly one third of interviewees (29%), including some who reported using fail words, used euphemisms or alternatives. For example, Cheryl offered:

I still don’t think that I ever used the word fail ... I think it always has such a negative connotation that I’m just naturally programmed to not even use that word. I know that I probably used that it is not successful, it is not working, that kind of stuff. (Cheryl)

Although Cheryl did not mention this specifically, three interviewees (21% of all interviewees) offered concerns that using fail words at all or often may suggest to students that the *students* are failures or that they failed. April mentioned, “I don’t want the kids to feel like they were a failure or that they failed.” As evidence for her concern, in April’s class, after she had used the word

“failed” to describe the point at which a design failed within the *Evaluating a Landscape* unit, a student exclaimed loudly, “I am not a failure!”

Encouraging Students to Reference Background Information. In an earlier section, we shared that Joy mentioned that a team of students responded to failure by deciding to consider background information for their improved design. They used what they had learned about the strength of arch and deep beam bridges in their second design, which was greatly improved from their first, failed bridge design. Although said that she had not intervened in this particular case, she shared an example from the *Evaluating a Landscape* unit where she was somewhat more suggestive of using background information after a team’s first TarPul design had failed. She was hesitant to be too direct, but offered:

... in my passing behind [a team] I said something like, ‘based on what we’ve done the past few days, we can recover [from failure]. What do we do that allows the TarPuls to be stronger?’ I think at that point they were able to think about ... the type of soil. (Joy)

Jessica also shared that she encouraged students to consider the strongest bridges from an earlier investigation when students were considering why their first design bridges failed. She asked: “What bridge was the strongest?”

Withholding Judgment about Design Failure or Success. Survey data revealed that few teachers responded to students whose designs had failed with judgment statements (e.g., “It looks like your design failed.”). None of the interviewees indicated that they used any such judgment statements. Two, however, explicitly stated that they did not encourage such judgment by peers or judge design success or failure themselves. Crystal encouraged teams to offer one another feedback about their failed designs and how to improve them. In so doing, she shared, “In some groups, I feel I had to continue to look at them and say, ‘No, now, we’re not judging them if it didn’t work – we just want to ... get this positive feedback.’” Joy described:

I tried to do my best to keep an even tone when I was observing a group or working with them ... so that I wouldn’t, like, bias what they interpret to be failure or success. I just like, matter of fact, said, ‘Oh, so your group was able to hold X amount of weight’ or ‘your group was able to pass the barge underneath’ – so just stating very factually what happened.” (Joy)

Later, she described that she tried “to keep a blank face” and “made it a priority to make sure that I’m not showing disappointment, like ‘oh you failed ... I didn’t want to give off that opinion to them.’”

Providing Direct Advice and Guidance. Interviews elucidated cases in which teachers provided very direct advice to teams whose designs had failed. This code emerged within the second round of interview coding and, due to the brief nature of ‘other teacher responses’ survey data, was not identified within survey data analysis. Roughly two thirds (64%) of interviewees described occasions in which they provided direct advice and guidance to teams who struggled to respond productively to a failed design. April stepped in to help resolve a team dispute (involving some crying) regarding whose ideas would be tried first in an attempt to improve after

a design failure. Team members could not decide, and to move things along, April made a decision that the group would use one girl's idea first, and that perhaps a third design could incorporate the other student's idea. Cheryl and Anna both referenced particular groups that required direct advice. Although many groups in Cheryl's class had strong team members to guide decision making after design failure, one in particular did not; about this group she said:

I had to prompt them a lot, to ask them questions about: 'What do you think about this, what do you think about that? Have you tried this? Or Have you thought about this?' I felt like I had to be a lot more guiding with them. (Cheryl)

Anna explained that while she used questioning to engage students that "just sat back," she used more direct strategies with students who were visibly frustrated. "Asking questions of the kids who were visibly frustrated," said Anna, "seemed to only escalate their frustration so with those kids I was more prescriptive."

Jessica, Teresa, Crystal and Bernadette mentioned offering very specific design advice, such as reducing a particular material, favoring a high strength score instead of reducing cost, and making designs that were simpler or more likely to be successful. Sean and Bernadette both mentioned providing failure analysis for their students' alarm circuits when students could not figure out why their circuits failed. Sean shared, "We kind of tried to come up with ideas together on how we could fix that. I also showed them how [and] where their errors were with their wiring."

Not Intervening. In contrast to offering direct advice and guidance, some interviewees (36%) described avoiding providing such advice or not intervening as students grappled with design failures and what to do next. Diane, who described herself as "not an overly warm and fuzzy teacher," said that she "was very cognizant of not giving them a lot of suggestions ... [and] letting them find their way." Joy, who, as mentioned previously, did not want to communicate judgment about design success or failure, was similarly inclined to let students take the lead even when her own learning experiences could help students create a more successful design:

Yes and they [a team] made me think back to the past summer where my partner and I we made our bridge and we weren't able to cross. So I'm thinking, 'Well, maybe these kids will be able to use the abutments and use a pier to support the cup region [where the weights will be placed].' They didn't generate those ideas, and it's not that I don't want to lead them to a way that might be more efficient or more effective. I want to see what they could come up with.

While neither Diane nor Joy offered examples of providing direct instruction to students, Jessica did. Despite this, she also seemed to value non-intervention and offered:

It's hard to be present to everyone and sometimes when you are present, it's not a good point to intervene. Sometimes you need to know when to be quiet and to let them sort things out on their own. ... It's definitely asking more questions than it is telling. If you're telling too much, then I don't think you're doing it right. (Jessica)

Not Needing to Encourage. While many survey respondents (23% of 35 teachers who provided ‘other teacher responses’) and interview respondents (36% of 14) shared that they offered general encouragement to students, two interviewees mentioned that they did not and did not have to. Penny shared that while she asked students questions to help them troubleshoot, “I didn’t need to inspire.” Her students were motivated and persistent, even when their designs failed. Her bigger challenge was slowing students down and getting them to think methodically. April, shared that she “didn’t feel that strong [of a need] to cheerlead” a group who, despite having a failed design, was spirited and enthusiastic about trying something different.

Conclusion and Discussion

Design failure – or a lack of design success – was a regular occurrence during EiE unit instruction, impacting multiple teams within most of the teachers’ classrooms. Students responded to design failures in various ways, and teachers, in turn, responded to students. Here, we summarize student and teacher responses, propose a model for thinking about student-teacher response dynamics around design failures, and consider fail word use and the possibility of unit and other contextual influences on student and teacher responses to design failure.

Student Responses

Teachers reported a range of student responses to design failure, including both positive, resilient, and productive responses and negative, non-resilient, and non-productive responses. Table 11 summarizes these responses as gleaned from both survey and interview data,

Table 11. Summary of students’ responses to design failure.

Resilient, Productive Actions	Non-Resilient, Non-Productive Actions
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 Making changes to design without planning or thinking carefully
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

juxtaposing certain positive, resilient, productive responses (e.g., trying again) with negative, non-resilient, non-productive responses (e.g., giving up). Responses mentioned by two or more teachers are included in Table 11 to demonstrate range; the frequency with which teachers mentioned particular responses can be found in the findings section.

In addition to these student responses, other ideas about student responses to failure did not necessarily fit into this positive/negative dichotomy. Examining others' designs, for example, may be regarded by some teachers as cheating or copying, punishable in most educational settings. Students may also preemptively respond to design failure by ignoring constraints and criteria; in this way, the design failure has not yet occurred, but its presence looms, encouraging, for example, an extra and unaccounted for scoop of oil in an oil spill clean up process or a hastily assessed plant package.

One comment by Cheryl deserves repeating here, as well. She offered that the responses in her classroom were typical of those she observes during the rest of the school day. Extrapolating from this a bit, it is highly likely that Cheryl and other teachers inside and outside of the E4 Project would say that some of their students tend to give up easily or persevere, think carefully and methodically about how to approach a problem or make quick decisions or careless mistakes. Perhaps, however, these tendencies should not necessarily be presumed to be consistent across all subjects for a particular student; for example, a student may persevere and want to try again in an engineering challenge, but give up readily in the face of a math problem (or vice versa). Perhaps more important is that the range of responses that students have in response to design failure is similar to the range of responses teachers are likely to see in other areas of instruction. The responses are not so different than what teachers are accustomed to observing, considering, and in turn, responding to with scaffolding as necessary.

Teacher Responses

Teachers responded to students whose designs were unsuccessful in a variety of ways (see Table 12). In the "General" category of teacher response were general encouragement and questioning. These were broadly applicable and mentioned by teachers throughout both qualitative and quantitative data. Questioning often took the form of the various kinds of responses included in the "Specific Interventions" category. Students were prompted to thoroughly engage in the Improve step of the EDP, use their peers as resources, and make connections to past learning experiences and the real world.

Non-intervention seemed to be a reasonable approach when students were responding in resilient and productive ways, or working towards such approaches as they negotiated within their teams. Recall Jessica's assertion that "sometimes you need to be quiet and let them sort things out on their own." Non-intervention might also be a general approach employed by teachers like Diane, who felt that her students were too often coddled; she used the same non-interventionist approach when teaching mathematics. Even encouragement was not necessary for one teacher, in whose classroom the design challenge was encouraging enough to engage and interest her students. Providing direct advice and guidance was necessary in some cases where students were immensely frustrated – and would be frustrated by further questioning – or where,

for example, electrical circuits containing student-designed switches were too difficult for students to interpret.

Table 12. Summary of teachers’ responses to students whose designs have failed.

Categories	Teacher Responses
General	Offering general encouragement Asking students questions
Specific Interventions	Prompting engagement in the EDP, especially the improve step: <ul style="list-style-type: none"> • Encouraging students to consider how to improve • Encouraging students to engage in failure analysis Encouraging students to use peers as resources: <ul style="list-style-type: none"> • Encouraging students to work more effectively in their teams • Encouraging students to observe others’ designs Encouraging students to make connections: <ul style="list-style-type: none"> • Help connect design failure or next steps to real world engineering and technology • Encouraging students to reference background information Providing direct advice and guidance
Non-Interventions	Refraining from offering judgment about the success or failure of the design Refraining from intervening Offering general encouragement only when necessary

A New Model of Student Teacher Dynamics around Design Failure

Earlier in the paper, we used a simple diagram to depict the overarching purpose of the study – to examine student responses to design failure, and, in turn, teachers’ responses to students whose designs had failed (see Figure 1). To better capture the nature of student and teacher responses to student design failure, we propose a new diagram (Figure 6). The diagram proceeds through three stages, yet the students/teacher may not proceed through all three. In the first stage, students initially respond to the failed design (see #1 in Figure 6); this response includes the range of responses captured in Table 11. We begin here by assuming that some response (even “not caring”) is elicited from the failed design. Teachers then have an opportunity to respond to the combined Failed-Design-and-Initial-Student-Response (together in the top, rounded solid box). S/he may choose not to intervene or to do so in general or specific ways as described in Table 12 (see #2). After this intervention – especially for initial student responses that are negative, non-resilient or non-productive – students may alter their response to the design failure (see #3). Ideally, the new student response is more positive, resilient and productive; however, as some teachers in the E4 Project experienced, it might not be. The new student response may involve a reconsideration of the failed design based on interactions with the teacher (depicted by the dashed rounded box and dashed arrow). This cycle may iterate, with teachers returning to students more than once to intervene and elicit new student responses to design failure.

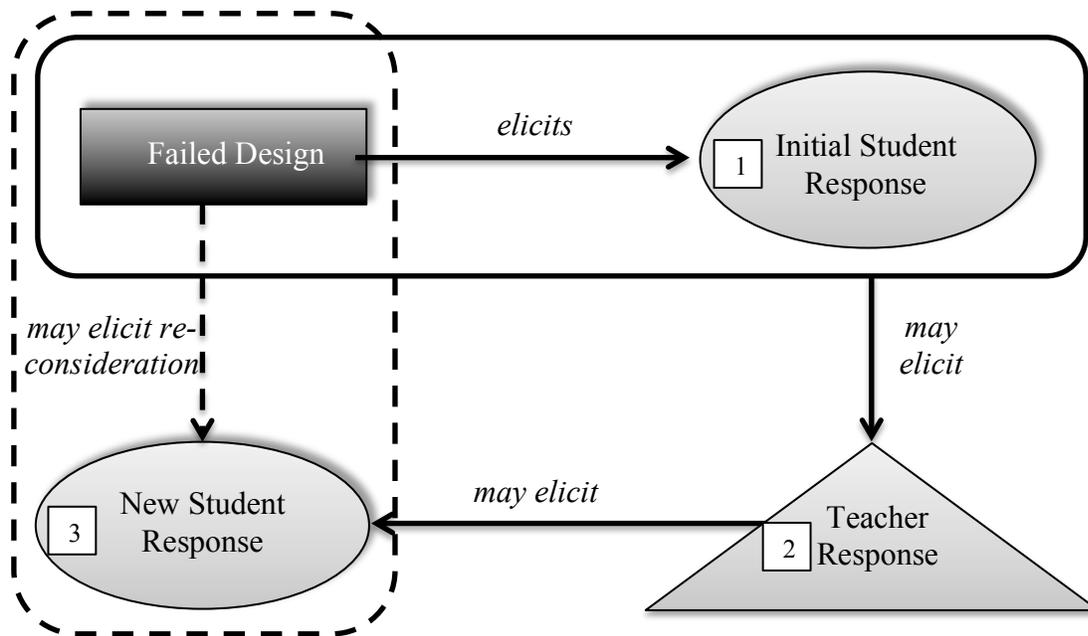


Figure 6. Model of dynamics between teacher and student responses to student design failure.

Fail Word Use

Teachers reported that they tended not to use fail words when responding to students or during engineering instruction, favoring the use of euphemisms and alternatives like “it didn’t work.” Some worried about students identifying as failures, and if they used fail words, were careful that they were associated with the design, not *you*, the student.⁶ However, others seemed to associate failure with students – e.g., that they failed the challenge – which is more akin to the use of fail words within typical educational settings. Teaching one or two engineering design units may be enough to shake the negative connotation that failure has within education and that many teachers bring with them as they learn to teach engineering.⁵ Tammy articulated this well when she offered that she simply found it “hard to get over this word [fail] being used in a non-negative context.”

Implications and Future Work

This study employed a convergent parallel mixed methods design to explore teacher reports of the way in which students responded to design failure, and the way in which the teachers themselves responded to students whose designs had failed. The study makes a novel contribution to the P12 engineering education field, which both: 1) argues for the merits of student engagement in engineering design and its associated failure experiences,^{7,8,9,10} and 2) has very little published research on what design failure experiences look like for students, how students respond to them, and how teachers can prepare for and respond to failure experiences during engineering design challenges.

By documenting EiE E4 Project teachers' reports of student responses to failure, we enable elementary teachers to envision how their students might respond in similar situations. Even if the concept of students developing a design that fails is of concern to teachers, the student responses that we have documented should look familiar – e.g., frustration, persistence, working productively (or not) within a team, resisting an improvement process – to most teachers in elementary environments teaching problem solving strategies in mathematics or the writing process. Similarly, teacher responses to students whose designs have failed employ very typical pedagogical strategies at work in elementary classrooms where teachers routinely: ask questions; make decisions about when to intervene, scaffold, or provide more direct instruction; and encourage their students to make connections across subject areas or participate in peer learning experiences. Sharing and discussing this range of student and teacher responses would be a productive addition to pre-service teacher education or teacher PD for those learning to teach engineering. While engineering learning experiences should help teachers differentiate failure in engineering design from failure typical educational settings, these learning experiences can simultaneously show how student and teacher responses relevant to design failure are likely to be similar to student and teacher responses in other, more familiar subject areas.

Future Work in the E4 Project and Beyond

There are many other ways in which future studies can build upon this work. We will continue to investigate design failure and fail word use within the E4 Project. The E4 Project is continuing to collect video data, interview data, student work, etc. in its second year (2014-2015). We wonder how teachers in the project describe design failure experiences and student/teacher responses relevant to those experiences after teaching EiE for two years – which may amount to a total of two or four units. We suspect that comfort and self-efficacy in teaching the assigned and *Bridges* units will increase, and wonder if there will be a commensurate increase in comfort and self efficacy related to using fail words, teaching about failure, responding to student design failure, etc. in the context of engineering instruction. We also intend to explore the way in which different curricular units influence the nature of failure experiences, and impact the extent to which fail words are used by students and teachers.

One critique that can be made about this study is that it relies on teacher reports of students and their own responses. While we feel that these reports are reasonable given our other interactions and field observations, we will be better able to support our findings as we begin to analyze video data from Case Study Sites to examine student reactions and student-teacher interactions around design failure experiences. This work is ongoing. Further, we will explore in these video excerpts not only the students' initial responses to design failures, but also their subsequent responses and actions after teachers have intervened (#3 in Figure 6).

We also wonder what kinds of Scientific and Engineering Practices (within the Next Generation Science Standards) and engineering habits of mind students use as they engage in failure analysis and improvement after design failure.^{8,11} In the second year of the study, when EiE E4 Project teachers have already taught the units once in the year prior, do these practices and habits – for example, communication and collaboration – improve between the *Bridges* and assigned units? Is there more evidence that students are able to *practice* the Scientific and Engineering practices, the anticipation of failure, and other engineering habits of mind?

Finally, we hope to compare fail word use and other aspects of failure in engineering design between the EiE and comparison curriculum teachers within the study, and investigate if students and teachers address design failure experiences differently in schools in different demographic settings. We look forward to researchers studying design failure experiences in P12 classrooms to build this important conversation in the engineering education community.

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APPENDICES

Appendix A-1: Survey questions: Teachers were asked to:

- A. Estimate the percentage, in 10% increments – ranging from less than 10% to 100% – of students who had a successful design by the end of their assigned unit.
- B. Describe some of the ways students responded when their designs in the assigned unit were unsuccessful.
- C. (If applicable) Estimate the percentage, in 10% increments – ranging from less than 10% to 100% – of students who had a successful design by the end of their *Bridges* unit.
- D. (If applicable) Describe some of the ways students responded when their designs in the *Bridges* unit were unsuccessful.
- E. Indicate by “selecting all that apply” which, if any, of the following 13 responses they used when students’ designs did not meet stated constraints or criteria:
 1. It looks like your design failed.
 2. It looks like your design was a failure.
 3. It looks like you failed the challenge this time.
 4. It looks like your design did not work as you had hoped/planned.
 5. We all make mistakes.
 6. We all fail.
 7. Why do you think your design failed?
 8. Why do you think your design didn't work?
 9. How can you fix your mistake?
 10. How can you prevent a similar failure in the future?
 11. Let's try again.
 12. Don't get discouraged.
 13. This is an opportunity for us to learn.
- F. Include any other examples of things they would say to a team that produced an unsuccessful design that are not included above?” If the teacher indicated “yes,” a text box stating, “Please explain,” appeared.

Appendix A-2: Synopsis of Interview Protocol Questions for Case Study Site Teachers

Teachers were asked:

- What a successful design looked like for the unit(s) they taught, and to estimate how many teams achieved design success for the first and subsequent designs within the EDP.
- What an overall successful design experience would look like for the unit(s) they taught.
- The range of student reactions when teams did not succeed in their first design.
- The different ways they responded to students who did not succeed in their first design.
- Specific examples from their classrooms in which: a team’s first design performed poorly, but the second design was more successful, and a team’s first and second designs both performed poorly.
 - Ways in which students responded in these cases.
 - Ways in which they (the teacher) responded to students in these cases.
- How, if at all, they used fail words during unit instruction.
- How, if at all, the curriculum, their own teaching strategies, or other curricula outside of the project may have helped teach students “how to fail.”

ⁱ The term, “habit of mind,” was originally used by the American Association for the Advancement of Science in *Science for All Americans*, and referred to “values, attitudes, and skills ... because they all relate directly to a person's outlook on knowledge and learning and ways of thinking and acting.”³¹ The National Research Council/National Academy of Engineering Committee on K-12 Engineering then adopted the term, engineering habits of mind, in its 2009 report.¹¹ In the report, the Committee argued that promoting engineering habits of mind was one of three principles – including an emphasis on engineering design and the incorporation of science, technology, and mathematics – that should guide precollege engineering education. The report stated that such habits of mind “include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations,” but did not suggest engineering habits of mind were limited to these six.³² Failure was not included in this report, yet was discussed in the report primarily from the viewpoint of failure analysis and limits discussion to the topic as a reference to the inclusion or absence of such analysis in the early offerings of “engineering” instructional materials.

ⁱⁱ Since this curriculum – and its comparison with the Engineering is Elementary (EiE) curriculum is not a focus of this study, it will not be discussed further here. This is a subject that will be elucidated in other and future E4 Project papers.

ⁱⁱⁱ A future paper will include a more in-depth investigation of the use of the words fail, failed, and failure in EiE and other curricula.

^{iv} Unfortunately, not all of these teacher discussions were documented/recorded.

^v We avoided using fail words in this and other question due to the loaded nature of fail words for teachers. For us, the meaning of this question is the same as asking teachers to “provide examples of things you would say to a team that produced a failed design.” However, if teachers believe that failing only occurs if students gave up (a belief some hold), then they might not answer this question at all.

^{vi} While not statistically interesting given that these data are qualitative and taken from a small purposive sample, these percentages given an indication of how often interview participants mentioned student responses. Similar percentages will be given for teacher responses.

^{vii} This and all other names used in the study are pseudonyms.

^{viii} A table of p-values and effect sizes for all possible response pair combinations is available upon request from the first author.