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Katarina N. Silvestri
*State University of New York (SUNY), Cortland*, katarina.silvestri@cortland.edu

Mary B. McVee
*University of Buffalo, SUNY*, mcvee@buffalo.edu

Lynn E. Shanahan
*University of Buffalo, SUNY*, leshanahan@gmail.com

*See next page for additional authors*

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## Keywords

engineering education, elementary school, design failure, positioning theory, interaction

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## Authors

Katarina N. Silvestri, Mary B. McVee, Lynn E. Shanahan, and Kenneth English



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Katarina N. Silvestri[1], Mary B. McVee[2], Lynn E. Shanahan[2], and Kenneth English[2]

[1]*State University of New York (SUNY), Cortland*
[2]*University of Buffalo, SUNY*

**Abstract**

This qualitative study applies Positioning Theory to identify positions that mediate the experiences of design failure within the context of an afterschool engineering club (EC) with elementary students diverse in language, race, ethnicity, gender, and academic abilities. We ask: (1) What kinds of structural design failure and failure responses did participants in EC experience? and (2) What are students' and teachers' positions in relation to responses to design failure? Types of positions (e.g., builder, tinkerer, idea-elicitor, director, observer) were identified in relation to children's and teachers' actions and speech in response to structural design failure during EC. Participants included 12 third-grade students and four teachers involved in EC for eight weeks. Data sources include audio transcripts, video, and field notes. Twenty-four design failure episodes were identified and transcribed multimodally from video, followed by coding of episodes using a multimodal Positioning Theory analytical framework. Findings discuss the kinds of engineering design actions and associated positionings unfolding in response to failure as well as the positions mediating teacher and student responses to design. We highlight the importance of student and teacher mediation as well as how Positioning Theory can be used to expand our understanding of (re)positionings that can occur within responses to design failure. Specifically, elementary engineering curricular materials must create the context to support the range of positions taken up in response to design failure. This includes explicit modeling of discursive actions surrounding design failure, multiple opportunities for students to experience and respond to design failure with time to improve beyond the design–build–test model, and support for teachers to address the range of students' responses to design failures knowledgeably and flexibly.

*Keywords:* engineering education, elementary school, design failure, positioning theory, interaction

## Introduction

Ben and Dimitri are multilingual students participating in an afterschool literacy and engineering club. Ben is an emergent bilingual learner who has been in the USA for six months. Dimitri, also identified as a bilingual learner, is proficient in conversational English. Trying to overcome a problem, they huddle over their rubber-band-powered car (Figure 1):

**Dimitri**: "It's hard Ben, very hard."
**Ben**: "But if we two work together…"
**Dimitri**: "It's not gonna be too hard, cause we two have great ideas."

*Figure 1*. Ben[1] (left) and Dimitri (right) problem-solve while building a rubber-band-powered car.

The Engineering Club was a school–university partnership with shared goals: (a) creating a supportive and collaborative space, particularly for populations underrepresented in engineering, to engage in engineering design and (b) providing conceptually rich learning opportunities for all learners by using disciplinary literacies and multimodal communication. This qualitative study of children diverse in language, race, ethnicity, socioeconomic status, and gender applies Positioning Theory to identify positions that mediate the experiences of persisting and learning from structural design failure (Cunningham & Kelly, 2017; Johnson, 2019) in the context of Engineering Club. We investigated the following research questions:

1. What kinds of structural design failure and failure responses did participants in Engineering Club experience?
2. What are students' and teachers' positions in relation to responses to design failure?

### *Responses to Design Failure in Elementary-Level Engineering Education*

The Next Generation Science Standards (NGSS Lead States, 2013) increased emphasis on engineering in K-12 education, boosting research on pre-college engineering education, including studies specifically about failure with elementary-aged students. Undergirding much of this growing literature is writing by Petroski (e.g., 1985, 1994, 2012) who has discussed the normative role of failure in engineering design writing, indicating that engineers should anticipate and use what is learned from design failures in the effort to ultimately construct the most successful final product. However, "failure" can be a negatively framed term in pre-college educational spaces (Johnson et al., 2021). A critical rationale for studying failure in elementary spaces where engineering curricula are taught is the tension between design failure within initial prototypes as normative epistemological practice in engineering and failure in the general K-12 landscape (Johnson, 2016, 2019; Johnson et al., 2021; Lottero-Perdue, 2015; 2016; Lottero-Perdue & Parry, 2017b), including responses to design failure in K-12 learning contexts.

#### *Exploring Responses to Design Failure in Engineering with Elementary Students*

Lottero-Perdue (2015) defines design failure as when an engineer's designed solution (or part of it) does not meet criteria outlined during the design problem and notes that design failure usually occurs during testing after either the create

[1]Caregiver consent and assent from each child as well as consent from all adult participants were provided to us per our IRB protocol; this includes the sharing of data (e.g., speech, photos) in dissemination of research findings.

(building) or improve (redesigning) phases of the engineering design process (EDP). Andrews (2016) reiterates that design failure is an important part of engineering practice that provides students feedback about their designs.

In pre-college education, failure is historically conceptualized as a negative outcome for students. As such, emotional responses and identities are usually implicated when failure occurs (Lottero-Perdue, 2015; Lottero-Perdue & Parry, 2017b). Lottero-Perdue (2015) describes how failure in talk and action are avoided in schools, since students (and teachers) associate making mistakes with being labeled a failure and taking on what is termed a failure identity. In the context of elementary engineering classrooms, failure identities are constructed through responses including negative emotions and actions like giving up, not planning out design changes, being competitive, seeking "correct" answers from teachers, and not using background concepts helpful to solving the problem (Johnson, 2016; Lottero-Perdue, 2015).

There are important considerations for how failure is typically discussed, practiced, and responded to in schools and how this could affect students' engagement with design failure in engineering contexts occurring in K-12 learning environments. For instance, Andrews (2016) focuses on elementary students' actions within testing cycles that tend toward design failure and how their responses impact iterations of students' designs. Importantly, engineering tasks can be purposefully embedded with multiple opportunities to experience, respond to, and analyze design failure through use of ill-structured problems (Jordan & McDaniel Jr., 2014) or making space and time for students to engage in multiple iterations of building, testing, and improvement (Andrews, 2016). When students have more opportunities to fail, respond to failure, and analyze those design failures supportively, students are able to consider more factors and ideas pertaining to their solutions. Such considerations can reveal a deepened sophistication in design thinking and problem solving compared to engineering tasks where they are more successful with fewer opportunities to fail and subsequently redesign (Andrews, 2016). Contrasting design failure with other kinds of negative, school-based failure, Lottero-Perdue and Lachapelle (2020) demonstrate how elementary students recognize design failure as an accepted practice of engineering after having had the opportunity to respond to design failure in settings where it was consistently considered a normative part of engineering.

Such opportunities for students to analyze design failure can be embedded into learning environments in multiple ways, and these can help cultivate productive responses to design failure. For example, implementing gallery walks allows students to present their experiences of the design and testing phases of the EDP, solicit advice from peers, and devise improvements (Wendell & Kolodner, 2014). Jordan and McDaniel Jr. (2014) illustrate how students manage uncertainty and risk while responding to design failure in their teams together. During emotional responses in the face of failure, students respond in both socially supportive and unsupportive ways. Socially supportive instances between students show that design failure paired with uncertainty yields productive discourse amongst students, including knowledge-building and engagement in argumentation. Lottero-Perdue and Settlage (2021) analyze design failures and their responses with kindergarteners as they discuss how children negotiated trade-offs relating to building materials after experiencing design failure and redesign. Findings indicate that students sometimes apply scientific knowledge (e.g., the heaviness of the materials) and other times apply an ethic of care (e.g., ensuring stakeholders in the design problem were cared for) to inform their redesigns after failure. Opportunities to fail, respond to failure, and analyze design failures for possible improvements should be supported by teachers who are well-versed in guiding their development of productive strategies to manage what happens after design failure (e.g., their initial responses to design failure, identifying weaknesses of a design, etc.).

### *Exploring Responses to Design Failure in Engineering with Elementary Teachers*

Prior studies explored teachers' use of "fail" statements in the classroom and perceptions of failure, finding differences based on years of experience. Elementary educators new to teaching engineering convey responses indicative of typical understandings of school failure; that is, school failure is usually perceived negatively. Educators generally avoid using the word "fail" and its derivatives, instead using words like "mistake" or "not working" when design failure occurs (Lottero-Perdue & Parry, 2017b). This avoidance of using "fail" and associated terminology is also found in Lottero-Perdue and Parry's (2015) study of teachers' reactions to student design failure in the context of an engineering design class. Teacher perceptions of design failure are described as "quite real" and "not to be dismissed." Thus, a cultural shift in using the term is required to purposefully redefine failure language in engineering contexts (Lottero-Perdue & Parry, 2017b). Negative conceptions of design failure persist in schools because teachers' perceptions of failure more generally are entrenched not only in teaching practices but in the overarching culture of educational assessment as well as teachers' histories and personal experiences (Lottero-Perdue & Parry, 2017a). Johnson and colleagues (2021) go on to explain that this negative entrenchment of the meaning of failure in the broader context of education impacts how students conceptualize engineering design failure. In light of this, scholars have argued that teaching young children (and their teachers) engineering may hold the key to unlocking the cultural shift to move students and teachers toward embracing design failure as generative (Johnson, 2016; Lottero-Perdue 2015; 2016; Lottero-Perdue & Lachappelle, 2020; Lottero-Perdue & Parry, 2015; 2017b; Wendell et al., 2015).

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Time and experience make a difference in teachers' perceptions about design failure (Lottero-Perdue & Parry, 2017a), especially with respect to how they mediate students' responses to design failure. Teachers with over two years of experience teaching engineering with elementary children felt more comfortable using design failure-related language with students and thoughtfully supporting children through design failures. Lottero-Perdue and Parry (2017a) explain that scaffolding students to support their responses to design failure in engineering contexts should be a part of formative engineering education. Importantly, this means that teachers require a versatile understanding of the normative role of design failure in engineering. Teachers can gain such an understanding through access to curriculum foregrounding the EDP, learning about typical student responses to design failure, and developing a toolkit of teacher responses to design failure, including when to intervene or not. Andrews (2016) found in her study of students' responses to failure during testing cycles where failure is likely to occur that learners need facilitation in order to deepen their thinking around instances of design failure in order to improve their designs, usually through questioning and prompts. Furthermore, Johnson et al. (2021) explain that teachers' feedback is paramount in supporting students through design failure experiences, and that teachers should consider the possibilities of engagement during these feedback-sharing interactions with students. Effective teacher feedback included teachers encouraging students to collaborate and helping students identify areas of improvement and strategies to make those improvements within designs.

## Theoretical Framework

All practices that an individual takes up, including those associated with engineering, are grounded in positions (Harré & van Langenhove, 1991). Harré and Moghaddam (2003) describe positioning as "a cluster of rights and duties to perform certain actions with a certain significance as acts, but which also may include prohibitions or denials of access to some of the local repertoire of meaningful acts" (p. 5). Positions shift across time as individuals engage with one another or with learning events. In contrast to static learning traits or styles, positions are fluid and are constructed socially through discursive practices (McVee et al., 2019) including speech. For example, Dimitri positioned Ben in a collaborative and collegial way by saying, "We two have great ideas." Positioning also occurs through other modes (e.g., at one point, Ben used gestures and sound to convey an idea to Dimitri). Conceptual and material tools (Roth & Lee, 2007), gestures and proxemics (Herbel-Eisenmann et al., 2015), and objects and artifacts (McVee et al., 2021) reveal and create positions.

Positions created through talk, activity, artifacts, and actions mediate children's understandings of and interactions with design failure as both tool and sign (Vygotsky, 1978). Positioning acts as an interactional and outwardly focused means to achieve external activity and as an internally focused means of shaping and carrying out cognitive functions (McVee, 2011) grounded in sociocultural practices (Roth, 2014). In this study, external positions revealed in children's discourse and actions are viewed as representative of children's potential internalized and emergent understandings of design failure in the context of engineering design episodes. In Engineering Club, all learners were positioned through language, action, and interactions to actively take up identities as novice engineers.

These potential positions (i.e., children as engineers) attempt to shift learning away from teacher-led, verbocentric models that prevail in many school settings. Yet, positions taken up by children are not unproblematic. As Davies and Hunt (1994) observe, it is difficult to escape the binaries used to organize classrooms. Such binaries as girl/boy, teacher/student, native English speaker/non-native English speaker, good student/bad student, and even success/failure reflect prevailing power discourses of schooling and society. Disrupting these power-laden discourses is difficult, even when attempting to introduce ways that design failure can be productive and even desired within the scope of engineering.

Davies and Hunt (1994) acknowledge that not only words, but actions, spatial location of bodies, gestures, and other communicative modes figure prominently in positioning and power. In the context of this study, we thus conceive of positioning not only in the realm of words, but of what Davies (2003) refers to as body/landscape relations. While body/landscape relations include the constitutive force of spoken utterances, much of what takes place within classroom landscapes is governed by subject positions that have their origin in social moral orders pertaining to language, culture, gender, peer-to-peer relationships, and so on that extend beyond classroom contexts. These social moral, or normative, orders are represented and re-represented not only in the speech of children or children and teachers, but in the gestures, interaction with artifacts, bodily movement, and spatial constructs present in engineering activities and materials (McVee et al., 2021).

In the context of this study, types of positions were identified in relation to children's responses to structural design failure. As with any social context, some positions arose from the immediate environment. For example, in the Engineering Club, the teachers discussed the EDP. Therefore, some role-based positions relating to testing or redesigning were built into the social context by the teachers through their use of the EDP (e.g., tester). Other positions, such as "revoicer" (i.e., one reiterating a teammate's idea) or observer, arose inside the moment-to-moment unfolding of storylines surrounding project-based teamwork. Regardless of their origin, positions were viewed as socially situated, negotiated, and fluid. While analysis of positioning among students was foregrounded, teachers' actions were considered when interacting with students

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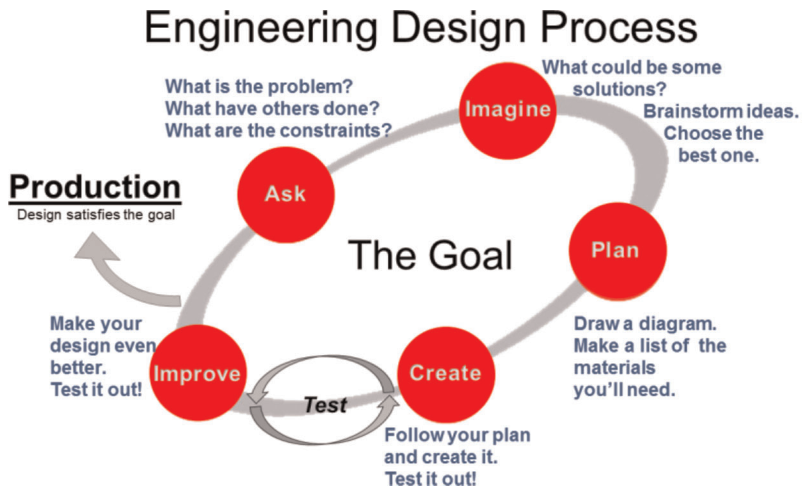


*Figure 2.* EDP model with guiding questions. Adapted from Cunningham (2009).

around episodes of design failure. Positions were analyzed through speech and also the modalities of gesture, action, and proxemics.

## Method

The methodological goals of this multimodal positioning analysis of an afterschool elementary engineering club were to (1) discern episodes of structural design failure, (2) derive positionings associated with responses to structural design failure, and (3) determine what responses to structural design failure accomplish and come to mean in the space of an elementary engineering club for students and teachers. Multimodal analysis (Kress, 2010; Norris, 2004) and discourse analysis (Gee, 2014; Starks & Trinidad, 2007) supported by Positioning Theory were used as the primary analytic methods.

### *Context*

The afterschool engineering club described in this study formed as a university–school partnership between a university in the northeastern United States and the nearby Legacy Elementary School (all names are pseudonyms). Legacy Elementary serves culturally, linguistically, and socioeconomically diverse Pre-K to Grade 5 students with a population that is Asian (18%), Black (16.5%), Hispanic (7.5%), and White (58%). Thirty-two percent of students at Legacy Elementary are labeled as "English Learners" by their district.[2] Forty-four percent of students receive free or reduced lunch, a common indicator of low socioeconomic status.

Through co-planning and professional development for elementary teachers, literacy researchers, and engineering faculty, Engineering Club evolved into a concentrated effort to (a) introduce children to engineering, (b) increase interest and positive attitudes toward engineering, and (c) build capacities for engineering-specific language and literacy skills. This was partially an answer to the national call for increased emphasis on science, technology, engineering, and mathematics in schools with hopes of sparking interest in children to consider engineering as a career choice (NGSS Lead States, 2013), especially for children whose populations are underrepresented in engineering (e.g., female, African-American, Hispanic). Engineering Club accepted all third-grade students interested in engineering.

### *Curriculum Overview*

Through co-construction of a curriculum, engineers, literacy researchers, and teachers responsible for teaching in Engineering Club sought to cultivate a culture of problem-solving and exploration rooted in engineering design with an overarching goal of generating interest in engineering in elementary-aged students. Lessons were constructed around engagement in the EDP referenced in Figure 2 (adapted from Cunningham, 2009). Engineering Club employed a workshop model, beginning with a whole-group minilesson, releasing students into small groups to solve design problems, and then ideally coming together as a whole group briefly to recap and reflect. The focus of minilessons included: (a) the six phases of the EDP, (b) defining technology, (c) form and function in engineering, and (d) how engineers learn from and improve their designs after design failure. Students engaged in the EDP to construct solutions to five project-based engineering

[2]We recognize the problematic nature of the label "English learner" as it may contribute to negatively positioning multilingual learners in school settings (see González-Howard & Suárez, 2021; Martínez, 2018). We use this term where it was used as a designation by the school.


*Figure 3.* Engineering Club curriculum overview.

problems: (a) pedestals; (b) bridges; (c) model landing systems; (d) candy bags; (e) rubber-band-powered cars (see Figure 3 for curriculum overview).

*Participants*

Twelve out of 24 third-grade students participating in Engineering Club provided parental consent and provided assent for this research with the following school-identified demographic breakdown: female: $n = 3$; male: $n = 9$; Asian: $n = 6$; Black: $n = 3$; Hispanic: $n = 1$; White: $n = 2$; "English learners:" $n = 6$. Students worked in groups of three to five which shifted from project to project. Four teachers (female: $n = 3$; male: $n = 1$; White: $n = 4$) also participated in this study and were the chief facilitators of Engineering Club. Teachers had 15 to 20 years' teaching experience. They were not previously experienced in teaching engineering; Mrs. Weber taught art, Mrs. Stasik was a library media specialist, Mrs. Erickson taught science, and Mr. Fisher taught fourth grade. Before and during Engineering Club, teachers engaged in ongoing professional development with engineering faculty regarding teaching engineering to K-12 students (Silvestri et al., 2019).

*Data Collection*

Engineering Club spanned eight weeks, meeting two days per week after school for one hour per session. Observational data corpora for small and whole groups include: audio transcripts, video (resulting in multimodal transcripts), researcher field notes, photographs, and student artifacts (e.g., drawn designs, built designs).[3] Data for triangulation include the scope and sequence of Engineering Club minilessons (Figure 3), daily lesson plans, and PowerPoint presentations associated with each lesson plan.

*Data Analysis*

Data analysis occurred across four phases: searching for focal episodes, collecting and organizing episodes, multimodally transcribing episodes, and positioning analysis. Drawing on techniques from discourse analysis (Gee, 2014) to identify episodes of structural design failure for analysis, searches were conducted of the observational data corpus for instances of any mention of failure using the search term "fail*."[4] Researchers' analytic memos and field notes used words to document the actions, emotions, and movements in Engineering Club as they unfolded through modes such as use of space, gaze, and

[3]It is worth restating that we collected caregiver consent and assent from each child as well as consent from all adult participants per our IRB protocol; this includes permitting the sharing of data (e.g., speech, photos) in dissemination of research findings.

[4]Use of the asterisk in print text search enables a search for parts of that word within the document. So using *fail** would yield all results involving *fail*, *failure*, *failing*, *failed*, *fails*, etc.

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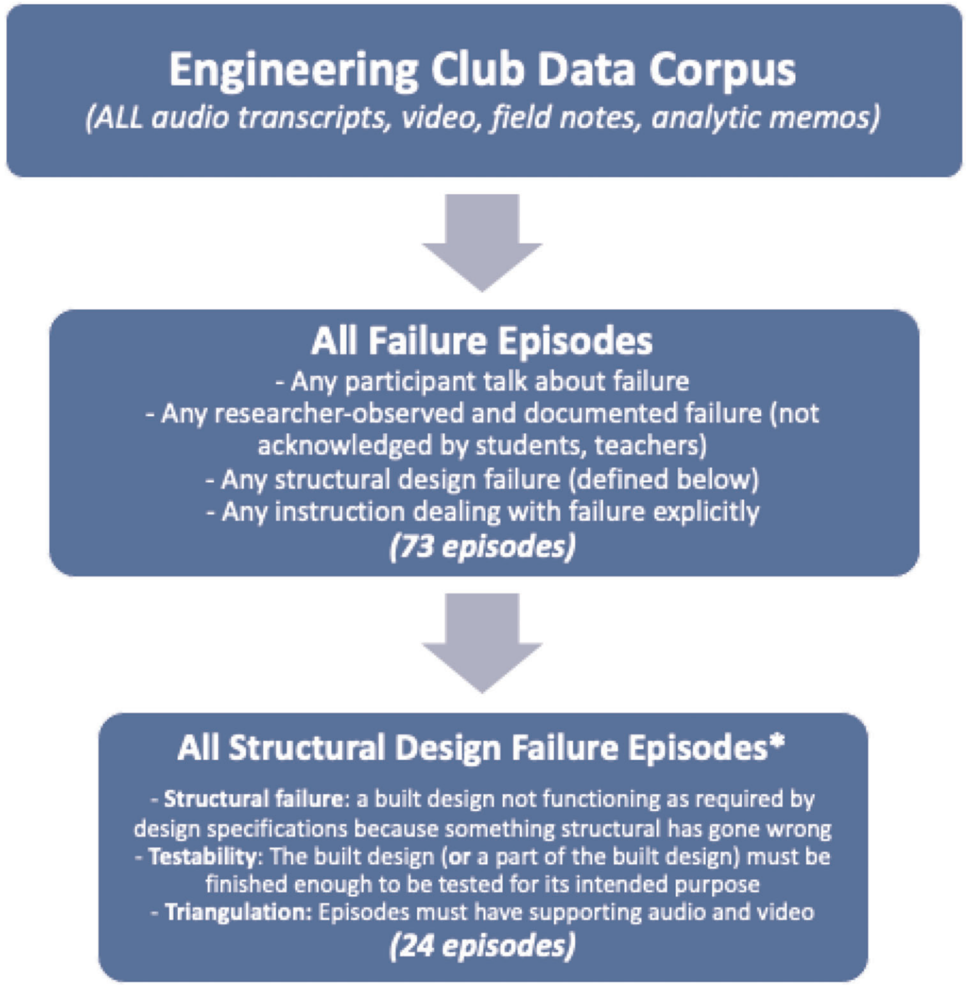


*Figure 4.* Focal data selection criteria. The asterisk denotes episodes analyzed in the current study.

proxemics, in addition to speech. Descriptions of failures as they occurred in Engineering Club were logged in these data sources. Therefore, doing a text search of the term "fail*" surfaced episodes regarding failure that extended beyond the mode of speech. This search technique was also instrumental in identifying corresponding video data and was repeated with terms similar to "fail*," including "mistake," "work*" (as in "not working" or "doesn't work"), "fix*," "improve*," and "redesign*." Using these search terms also surfaced multiple situations involving design testing, necessitating additional text searches using the words "test*" and "try*" in addition to culling through all videos for instances of students' testing for potential design failure episodes to consider in this analysis.

To collect and organize the episodes, spreadsheets documented: (a) data sources (i.e., audio transcript, field notes, video), (b) instructional groupings, (c) club date, (d) participants in the episode, (e) project where design failure occurred, (f) brief description of failure, and (g) locator indicating where this episode could be easily found in the corresponding data source.

Episodes fell into relatively distinct categories of: (a) structural design failure, (b) talking about failure, and (c) researcher-observed failure. Per the research questions, further analysis was conducted on episodes coded as "structural design failure." The reason for this was that structural design failure related consistently and concretely to student solutions for design problems and engagement with the EDP, whereas the other two types of failure identified were often about failure generally, and our research questions focus on structural design failures directly acknowledged by the focal participants (i.e., students, teachers) rather than simply observed by researchers. Figure 4 shows the process for selecting the final focal data, including the 24 focal episodes showing instances of structural design failure.

After identifying and locating all focal episodes on video, multimodal transcriptions were constructed, narrating moment-to-moment action, talk, and emotional energies of participants as the episode unfolded (Kress, 2010; Norris, 2004). InQScribe transcription software paired episodes with video timestamps. Memoing and annotation of focal episodes co-occurred with transcription as an initial level of analysis (Creswell, 2013). Annotation of multimodal transcriptions of focal episodes involved initial coding (Charmaz, 2006) of multimodal actions relating to modes of gaze, gesture, body proxemics, touch/haptics, materials-handling, observable bodily expressions of emotions, and talk. Annotations also denote when these multimodal actions occurred during Engineering Club, including specific times during the design process (i.e., solution generation, testing, building, materials exploration) including times involving teacher/adult intervention. Importantly, lower-level multimodal actions (e.g., gaze at failed design, talk between student and teacher regarding failed design, gesturing toward materials, emotions relating to design failure) that built up into higher-level multimodal actions (e.g., guiding students after design failure) during moments of and after design failure were recorded, described, and quantified.

Positioning analysis took place after multimodal transcription of focal episodes. Katarina and Mary used an existing positioning coding scheme relating to how participants positioned themselves and others in relation to artifacts (Silvestri et al., 2021) which identified engineering design actions (i.e., ideating, building, helping, observing, testing) and associated role-based positions (i.e., idea-sharer, idea-listener/observer, idea-eliciter, builder, active helper, observer, forced observer, tester). Katarina and Mary iteratively coded for different positions throughout the 24 structural design failure episodes in the focal data set, using the original actions and positions in the coding scheme and adding multiple new ones. These positions pertained to actions that were occurring directly before, during, and after design failure within the scope of the EDP. For example, the action of ***ideating*** (involving an idea or suggestion meant to solve a particular problem with the design) resulted in multiple role-based positions taken up by both students and teachers, such as ***idea-sharer***, ***idea-listener***, ***idea-eliciter***, ***idea-supporter***, ***idea-revoicer***, and ***director***. Katarina and Mary met to compare coded material around positions and come to consensus on these codes, resulting in a full coding scheme of role-based positioning around instances of design failure (see Appendix for all codes, definitions, and examples with asterisks indicating codes new to this study).

### *Researchers' Positionings*

Three authors (Katarina, Mary, and Lynn) were White, female university researchers with a background in literacy and emerging knowledge of engineering. Mary and Lynn were university professors of literacy, and Katarina was a research assistant. During Engineering Club, Katarina, Mary, and Lynn wrote field notes, took photographs to supplement field notes, and collected audio and video data. Kenneth was engineering faculty at the same university and participated in Engineering Club in an advisory role, providing professional development with K-12 teachers, helping to develop the Engineering Club curriculum, and observing some Engineering Club sessions and working with students. All authors helped Legacy Elementary partner teachers set up each session, providing supplementary curricular materials (e.g., PowerPoints, photos, YouTube videos) for participating teachers to use. During Engineering Club, researchers were moderate participant observers, defined by Spradley (1980) as researchers who maintain both an "outsider" role (e.g., taking field notes without intervening in student interactions) and an "insider" role (e.g., interacting with students requesting help and no teachers were available).

## Findings

In this section, we present findings to explain how teachers and learners respond to moments of structural failure. Findings are presented across two themes: *engineering design actions and positions in response to design failure* and *positions mediating responses to design failure in Engineering Club*.

### *Engineering Design Actions and Positions in Response to Design Failure*

Four kinds of design-centered actions unfolded in response to design failures, delineated in Figure 5 according to kinds of actions, sources of mediation, and frequency across episodes. These are the overarching actions children enacted upon the design itself in response to its structural failure. Embedded in these design-centered actions are positions taken up by students and teachers which mediate the actions taken. Teacher mediation included discussing design failures, eliciting ideas about causes of design failure, thinking aloud of potential improvements, and providing and occasionally modeling design suggestions with students' sketches or artifacts. Student mediation included discussing what went wrong, tinkering with materials, figuring out next steps in design improvement (e.g., design sketching modification, modifying artifacts), and providing advice to and/or soliciting advice from other students.

#### *Building On to Make Improvements*

Building on to make improvements was the most frequent action in response to design failure in Engineering Club. Very often, these improvements were necessary for designs to meet requirements and function properly. One example of teacher mediation occurred when Mrs. Erickson (science teacher), modeled how two parts of a design could fit together to create

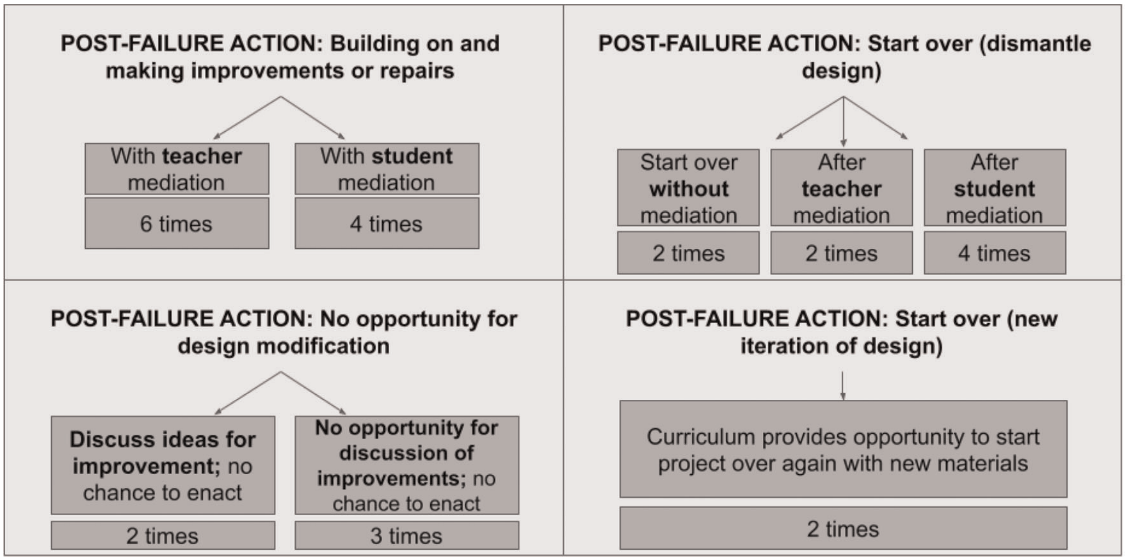


*Figure 5.* Actions unfolding after failure across 24 episodes.

*Figure 6.* Mrs. Erickson's modeling of improvement (i.e., joining two parts of the failed design).

something more stable. She positioned herself as ***idea-sharer***, while Dimitri and Hudson were positioned as ***idea-supporters*** (Figure 6). Her idea was later taken up by the group and tested.

Student mediation also led to building on or making repairs directly after design failure. An example of this was when Saabira, Ben, Fatima, and Emma tested their pedestal with the stuffed animal which led to their pedestal's collapse. Saabira, positioned herself as ***builder to improve***, immediately making modifications, flipping the design on its side and taping. To her side, Fatima observed Saabira's work and stated they "should actually, like, glue the sides [gesturing on the pedestal] here, and then we're done." Though Saabira dominated building, Fatima positioned herself as an ***improvement discusser*** and ***idea-sharer***, mediating Saabira's response to design failure as Saabira took up her idea of adhering the sides together.

*Start Over (Dismantling the Design)*

Dismantling the design meant that students took failed structures apart and started building all over again rather than make improvements on the existing design as described in the previous section. When groups responded to failure by dismantling designs, with either teacher or student mediation, they appeared more purposeful and positive in their sense-making of design failure and more effective in creating a working design. For example, Mrs. Erickson noticed Liam, Aiden, and Owen striving to get their rubber-band car to move in a straight line. Drawing on positioning and associated power dynamics frequently seen in educational spaces, she positioned herself in an ideating role as a ***director***, giving direct guidance in their deconstruction while the three boys were active ***idea-listeners***:

> **Mrs. Erickson**: You guys did an awesome job. Now here's what I want you to do. Other cars are going farther. You've got the wheels fixed. You've got it up on the body. You've got the rubber band working. Look at what kinds of rubber bands the other teams are using.

To follow Mrs. Erickson's advice, a full dismantling of the car was necessary, which Liam did purposefully and quickly. This eventually led to the group successfully meeting all design requirements.

Student-mediated dismantling also tended to entail purposeful direction inclusive of group members and their ideas. One example from the rubber-band car project showed James and Saabira beginning their first wheel–axle design. James acted as

*Figure 7.* Saabira and James tinkering in parallel with wheel–axle materials after design failure.

a ***problem-identifier*** when he deemed their wheel–axle design unsuccessful as the wheels were not straight. Saabira reacted as ***dismantler***, taking the materials out of James's hands, taking apart the wheel and axle, and then took up the position of ***tinkerer*** as she touched and experimented with the component parts. James subsequently took up the position of ***tinkerer*** as well, finding similar materials on the table and doing his own tinkering with the wheel and axle parts. They explored materials in parallel; it could be inferred that they developed some understanding of how such materials could work together to create a functional wheel–axle. This was demonstrated when both James and Saabira showed how a wheel and axle work together and when they could troubleshoot wheel–axle problems without teacher mediation (Figure 7).

In the cases where deconstruction happened rapidly and without clear mediation from either students or teachers, a single student took total control of the design work and decision-making, not seeking input from other team members. This response happened twice, and while a successful design was eventually yielded, the generally positive team dynamics of these groups were shaken, and disagreements ensued in ways that were less than productive. An example of this was the bridge design failure in James, Ben, and Liam's group.

At one point while building, the popsicle sticks cascaded down off the tape holding them together resulting in structural design failure. In frustration, James, as an ***evaluator***, told Ben and Liam, "This was good until *someone* [indicating Ben] touched the tape. Wreck it, wreck it!" This burst of negativity by James's evaluation of Ben being the source of their failure was coupled with James becoming a ***dismantler***, pulling the tape off the bridge and causing all of the popsicle sticks to fall from the platform. Eventually, as the three of them became ***dismantlers***, they worked to remove every single popsicle stick from the bridge. James continued: "*I'll* put the tape on. *I'll* put the tape on this time," and this caused Liam to get defensive which then led to a brief struggle over the tape. Liam repositioned himself as ***builder*** to improve, stating that "No, it can't be the same" and moved to cut a long piece of tape from the roll. Through all of this, Ben was a ***forced observer*** as James and Liam vied for power over the building materials. However, Ben appeared undaunted after the quick dismantling and became a ***co-builder*** with Liam to improve the structure. Though Ben was able to begin again, James was not receptive to conversation regarding salvaging the design. Discussion could have saved time and incorporated more voices into decision-making.

### *No Opportunity for Design Modification*

Due to curricular and time constraints, there were five instances of design failure that were neither able to be improved upon nor dismantled. These cases usually happened after testing a design until it failed, when there was neither enough time nor materials for students to construct a new design or build upon their existing one. However, teachers did make a point to open up spaces for students to discuss what they could do next time, if they had the opportunity. An example of this involved Jakob and Hudson's second attempt at designing the candy bags which was less successful than their initial attempt the club session before. After their bag design failed, Jakob began saying, "We should've…" which was cut off by Mrs. Erickson's compliment of, "I liked how you tried a different material," which positioned her as a ***design affirmer***. Mrs. Erickson doubled back and immediately re-opened space for Jakob's verbalization of his thinking as an ***idea-eliciter***.


*Figure 8.* Candy bag materials provided for iteration 1 (left) and iteration 2 (right).

**Mrs. Erickson**: Wait, what do you think that you should've done?
**Jakob**: Maybe we should've put it, like, more at the bottom [pointing to the handles on the bag]. Put it more at the bottom [gesturing along outside of bag] so then it would take longer to rip.
**Mrs. Erickson**: [revoicing] Oh! So next time, you would redesign it so that your handles were farther down?
**Jakob**: [nodding] Mhm.

Though Jakob never got to enact his idea because the club session was ending, and the next session moved on to the rubber-band car project, there was at least a space for him to think aloud about what he could do to improve their bag design, enacting the position of ***improvement discusser***. Unfortunately, this kind of teacher-guided mediation and positioning through discussion was not always possible after testing, especially when that testing was done in a whole-group setting.

*Start Over (New Iteration)*

Least frequently, and mostly due to the curricular design of Engineering Club as described above, students got a chance to start a second iteration of the same project after failure occurred in their first design. The ability to create a new design out of different materials for the same project parameters only occurred during the candy bag project. The goal, as designed by the teachers and researchers, was to test each group's candy bags until they failed. Then, the students would need to make choices as a team to decide how to improve their designs; the students were also provided with different choices in materials, as shown in Figure 8. This opportunity for redesign enabled students to take up positions tied to actions of problem-scoping, ideating, working with materials, and building—all related to making improvements upon their original design.

The aforementioned examples of actions following design failure have provided a glimpse into how students and teachers mediated these experiences and their associated positions. The next sections focus on how Engineering Club included different supportive patterns of participation from teachers (and researchers acting in a teacher role) and students.

*Positions that Mediated Responses to Design Failure in Engineering Club*

Teachers and students mediated responses to instances of structural design failure through their participation and positionings. We illustrate how responses to such design failures were co-mediated in Engineering Club between teachers, students, and the unfolding experience of design failure.

*Mediating Actions of Teachers Supporting Responses to Failure*

In Engineering Club, children required scaffolding from teachers to respond to design failure in more productive ways; teachers supported students through structural design failures in four broad ways: (1) promoting positive domain-related concepts about design failure; (2) guiding students after design failure; (3) (re)directing attention to the design; and (4) drawing attention to design failure.

*Promoting positive domain-related concepts about design failure.* It is worth reiterating that dominant school discourses negatively conceptualize failure (e.g., Johnson et al., 2021; Lottero-Perdue & Parry, 2015). Teachers helped mediate such negativity by affirming positive aspects of the failed design, drawing explicit attention to positive attributes when conversations of design failure arose. Jakob and Hudson's second attempt at the candy bag broke almost immediately during testing, and Mrs. Erickson remarked, "I liked how you tried a different material, though," since they attempted to make the bag out of foil instead of plastic. In another instance, that same teacher, impressed by the unique design of Ben and

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| Teacher/Adult Position | Example Speech Acts |
|---|---|
| Questioner/ Prompter | • "Is that the stopping point?" *(Mrs. Stasik, bridge testing)*<br>• "So is it safe anymore if [the bridge] is starting to break?" *(Mrs. Stasik, bridge testing)*<br>• "What did we get? What was the weight?" *(Mrs. Stasik, candy bag testing)* |
| Idea-Eliciter/ Idea-Revoicer | • "So hold on – why do you think [the wheel] was stuck like that?" *(Researcher Katie, rubber-band car building)*<br>• "Oh! So next time you would redesign [the candy bag] so that your handles were farther down?" *(Mrs. Erickson, candy bag testing)* |
| Director | • "You should get it off the bridge if it's starting to break" *(Mrs. Stasik, bridge testing)*<br>• "Before we start taking everything apart, remember, we don't want to start the whole thing over, we want to finish." *(Researcher Katie, rubber-band car building)*<br>• "Let's see if we can get that wheel on tighter, guys." *(Researcher Kate, rubber-band car building)* |

*Figure 9.* Guiding teacher positions speech acts around structural design failure.

Liam's failed popsicle-stick bridge, observed, "It *was* a beautiful design, though." Praise and complimentary language positioned Mrs. Erickson as a ***design affirmer*** which helped smooth over the initial shock of design failure, particularly when students were visibly distraught.

There were instances where teachers explicitly discussed positive aspects of failure, though this happened infrequently during and after structural design failure situations. In these instances, teachers were engaging in affirmation as they reminded students upset at their design failure that it is, in fact, "okay," and even desirable in the realm of engineering to learn through design failure. Taking risks and anticipating design failure during initial testing cycles are parts of the work that engineers do. For example, Mrs. Weber spoke to students directly about the nature of design failure in engineering when Ben and Liam's bridge design failed much earlier in comparison to others. She said, "Sometimes, engineers take risks; engineers don't learn these kinds of things unless they try, unless they take risks. Engineers, taking risks, trying different things." In this instance, Mrs. Weber positioned herself as an engineering ***identity affirmer*** for students. In Engineering Club, teachers taught a minilesson discussing why design failure is beneficial to engineers at the outset of the second design project specifically (i.e., the bridges); however, the aforementioned example with Mrs. Weber was the only explicit mention of design failure being beneficial directly *after* a structural design failure. It is notable that when teachers talked directly about design failure events, they avoided using the word "fail" or "failure." They also did not allude to making mistakes. While failure of a design was implied, it was not directly stated. Engineers were *not* often directly positioned as people who encountered design failure but instead as people who took risks and tried new things.

*Guiding students after design failure.* Most often, teacher verbalizations following structural design failure episodes involved guiding students to develop solutions to their design problem through questioning, directing, and eliciting ideas from students toward the next step (Figure 9).

*(Re)directing attention to design.* Notably, each of these phrases used by adults in Engineering Club around structural design failures pointed back to the design, design problem, EDP, or prior teacher guidance in some way. The focus was less on the design failure itself. Rather, the design problem and the multiple steps it entailed as a whole were framed as more important. There was attention toward maintaining productivity toward the next step. Interestingly, this kind of attention tended to happen in spaces where competition was *not* foregrounded and where testing happened in small groups with adult mediation. Unfortunately, several projects (i.e., pedestals, bridges, and model landing systems) had a single iteration of testing in a whole-group setting, which fostered a spirit of competition and winning rather than one of improvement in design. As such, competition manifested as end-goals for students rather than improvement of designs. In these whole-group testing scenarios, where all eyes were on a single group, students verbally compared themselves and their designs to one another in terms of their maximum capacities, positioning themselves as competitive ***test evaluators***. In addition,

teachers were rarely able to provide the kind of just-in-time guidance around design failure demonstrated in Figure 9 during whole-group testing. Teachers were instead positioned as ***observers*** and/or ***evaluators*** of the final outcome of testing.

*Drawing attention to design failure.* With relative infrequency, teachers acted as ***observers*** and ***evaluators*** drawing direct attention to the structural design failure after it occurred, making observations or explaining why students were unable to continue testing. Positioning themselves initially as ***observers***, these voiced observations of failure were simple, as when Mrs. Weber uttered "Oh, I thought the handle broke" or "It broke" during candy bag testing. In one instance of direct attention to the design failure afterwards, ***testers*** James and Dimitri made the case that since their second candy bag handle was not yet broken, they could still hold the bag and be acting within the design's parameters. At this point while looking at the bag Mrs. Stasik said, "Once one handle breaks…" and Mrs. Weber follows with, "Yeah, once we have a design flaw…" Through these words, testing for James's and Dimitri's bag is evaluated by the teachers as finished. This speech act invokes more typical teacher–student positioning and power dynamics. In this case, the teachers not only drew attention to the design failure, but explicitly attributed it to a "design flaw," evaluated this design failure as the reason for not continuing the test, and thus assumed candy bag design failure. Notably, once again, use of the word "failure" did not occur even when alluding directly to design failure. Instead, teachers were more explicit and direct about what had failed. However, by focusing on testing and results, teachers missed the opportunity to mediate discussions around topics such as "optimization" or "engineering analysis" (Purzer et al., 2021, p. 32).

*Mediating Actions of Students Supporting Responses to Design Failure*

As Engineering Club centered on students working in a self-directed, problem-based learning context in which they were responsible for designing the solutions to engineering problems, there was a great deal more between-student talk recorded referring to structural design failure episodes. Student mediating actions around failure were multipurpose, including (1) design and problem-scoping work; (2) exploratory actions toward improvement work (e.g., tinkering), and (3) reflective actions (e.g., reflecting, engaging in reasoning). These embodied actions, talk, and ensuing positions taken up are laden with materiality and the use of multiple modalities in interaction.

*Design and problem-scoping work.* During and after design failure, students engaged in work that revolved around the design, involving students commenting, critiquing, and directing each other based on the structural design failure itself (or the design failure-in-progress). Some of these observations were well-supported linguistically by verbalizing the nature of the design failure directly by enacting the ***problem-identifier*** position, such as when another student gestured toward Dimitri, Fatima, and Noah's bridge, commenting, "It's breaking. I could tell at the bottom." In another instance of ***problem-identifier*** position, the identified problems leading to design failure were plainly evident in the action that occurred with the materials directly, such as when Fatima said, "Aaaaand the wheel fell off," in response to the wheel falling off the axle onto the ground next to where she and Emma were testing. Other times, problem-identification involved stating a problem broadly, such as "It's not working" or "this don't work," without verbally elaborating.

In cases where students were moving beyond identification of a problem during or after design failure, they were judging, questioning, or directing. In Fatima's case, once again, what began as a ***problem-identifier*** position shifted into an ***evaluator*** position as she considered the material constraints of tape for that aspect of the car. Fatima gestured to specific parts of the car with her hands, stating, "See, that's the problem. I thought tape—it didn't work. I don't think tape is gonna be good." Other students' judgmental comments as ***evaluators*** were less nuanced, such as the student who stated, "Guys, it's bad," regarding Dimitri's group's bridge.

Finally, the complex interactions of James and Saabira illustrated how power struggles over designs, even within the same episode, encouraged as well as stifled opportunities to learn from design failure. James and Saabira tried multiple unsuccessful attempts to propel their rubber-band car on the track. After failed tests, they engaged in multiple arguments and power struggles pertaining to being the ***tester*** and testing properly (Figure 10). First, James was ***observer*** while Saabira

*Figure 10.* James grabs the car from Saabira, giving her directives.

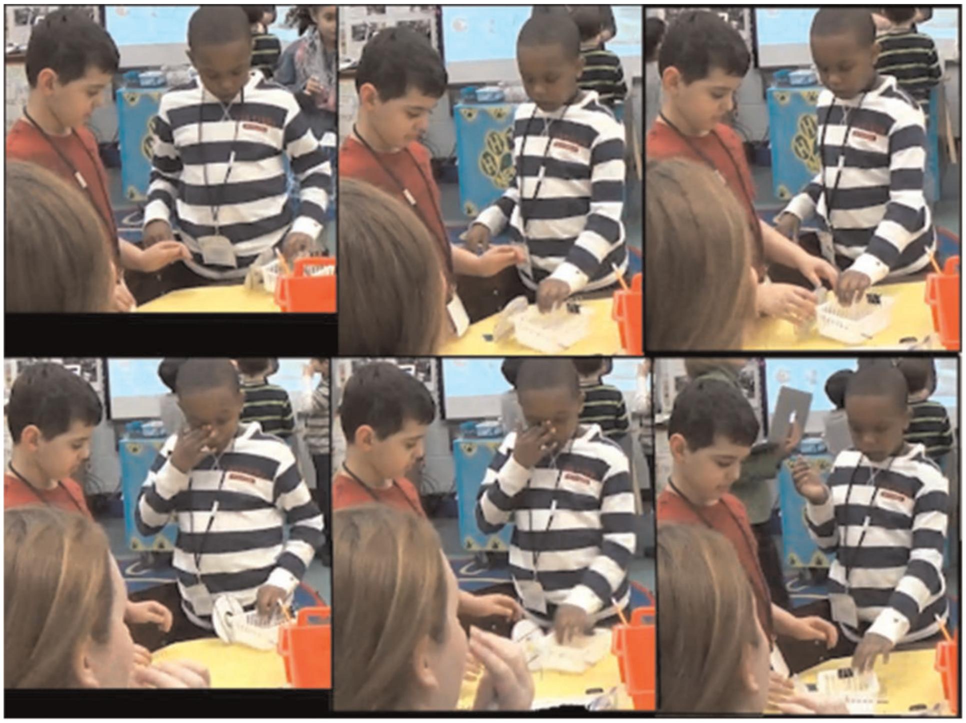

*Figure 11.* Owen makes multiple test rolls of the car, decides to use different wheels.

was ***tester***. James shifted into the ***problem-identifier*** position, indicating the car was not facing the right direction. James then placed his hands on the car, challenging Saabira's position as ***tester*** and attempting to assume control of the car. Saabira knocked James's hand away and continued to wind the wheels as ***tester***. However, James physically took the car from Saabira, repositioning it on the track, and directing her to follow his instructions. In this instance, he was also repositioning himself from ***observer*** to ***tester*** and ***director***. Throughout the episode, Saabira moved back and forth between being an ***observer*** and an ***active helper***, as she often placed her hands back on the car and followed James's directives (e.g., letting go of the car to test it). Here, another power struggle ensued. Saabira ultimately ended up taking control of the car, taking up the positions of ***tinkerer***, ***tester***, and ***idea-sharer*** while putting James in the position of ***forced observer***. In this instance, however, James shifted his positioning to ***distracted participant***. Interestingly, the first power struggle resulted in Saabira eventually cooperating (for the moment) with James to enact his idea, whereas the second resulted in James disengaging entirely while Saabira took up more active positions around the design.

**James**: You've got it the wrong way!
**Saabira**: I know what I'm doing.
**James**: No, you've got it the wrong way. It has to be *this* way, it drives *that* way. Now, let it go!

*Exploratory actions toward improvement work.* Through actions of suggesting ideas, questioning, making decisions, and then enacting those decisions, students moved through structural design failures into improvement or redesign phases of the EDP. Suggestions were directed either at a group's design or, in James's case, toward other groups' designs in an advice-giving capacity as an informed ***idea-sharer***. In Jakob's case with the candy bag shared previously, he additionally provided a rationale for his suggested change and why it could make the bag more effective. In another case, after acting as ***tester*** and rolling the wheels of their car across the table multiple times, Owen suggested to Liam they ought to use a different wheel, positioning Owen as a ***director*** and ***idea-sharer*** simultaneously (Figure 11).

Sometimes, actions around design improvement were less straightforward and more exploratory. After design failure, students might elect to take up the position of ***tinkerer*** engaging in materials exploration (Figure 12). This was especially pertinent during early stages of the car project, as students had at least double the materials available compared to their previous projects (i.e., pedestals [2 materials]; bridges [3 materials]; model landing system [8 materials]; candy bags [7 materials]; **rubber band cars [16 materials]**).

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*Figure 12.* Tinkering across groups (top row, left to right: 1. Liam, Owen; 2. Ben, Dimitri. Bottom row, left to right: 3. Emma, Fatima; 4. Jakob; episodes 17–20).

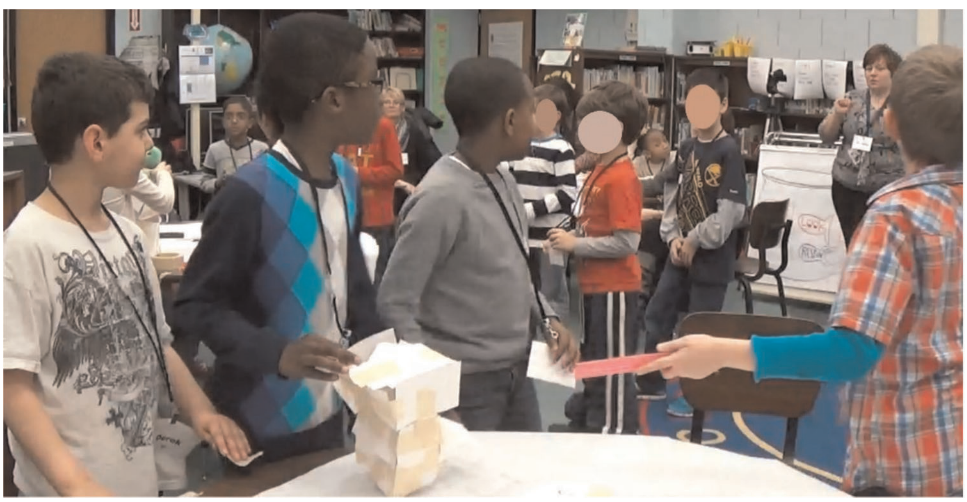

*Figure 13.* Liam, Aiden, and Owen (left to right) gaze toward Mrs. Stasik together after design failure.

*Reflective actions.* Structural design failure also created situations when students engaged in reflection and challenge through reasoning. While there were surface-level inter-group competitive comparisons between the performances of their designs during whole-group tests (e.g., "YES! Ours beat theirs!"), there were other instances where students were more nuanced in their reflection and reasoning. In these cases, students reflected on design requirements, previous design tests, and/or Engineering Club experiences in order to consider, compare, or challenge the failure at hand.

Aiden, Liam, and Owen reflected upon design requirements when their pedestal was being measured by another student. It became clear that their pedestal design did not meet the height requirement of ten inches and thus failed, initially surprising the group. All eyes were literally on Aiden's group and their pedestal which had been deemed a failed design, producing tension in the room embodied by all three members of Aiden's group (Figure 13).

In this interaction regarding design requirements, Aiden was positioned as ***problem-identifier*** and the student measuring the pedestal as ***tester***. The design failure produced a sense of possessiveness and protectiveness around the group's design, particularly for Aiden, as shown in this elaborated transcript:

[The group's pedestal has been measured multiple times by **Student**. **Aiden** grabs pedestal in both hands, picking it up off the table, drawing it to body. He appears stressed based on his pointed tone of voice.]
**Aiden**: [voice low-pitched] It's not [ten inches]!
[**Student** attempts to measure pedestal again with ruler; **Aiden** pulls pedestal away from **Student**.]
**Student**: [turned toward **Aiden**] It has to be [ten inches].
[**Aiden** turns towards **Mrs. Stasik** with pedestal in his hands. **Aiden** looks at **Student**, then turns to table with pedestal.]
**Aiden**: [voice low-pitched, pointed] Well, it's not.
[**Student** attempts to measure pedestal; **Aiden** puts pedestal back on table. Aiden turns attention toward pedestal through gaze. **Aiden** pushes ruler and **Student's** hand away with back of his left hand.]
**Aiden**: It's like eight inches, okay?

In this exchange, Aiden was acutely aware of the height requirements. When challenged about the pedestal's height, Aiden conceded the point but blocked the other student from measuring again. Aiden then estimated the true height of the pedestal aloud, and the student measuring pedestals moved to the next table. Later, Aiden was spurred to meet design requirements and acted as ***improvement builder***, quickly adding a roof structure to the pedestal. When the pedestal was measured again after redesign, it technically met height requirements.

Another example of reflection work involved James and Dimitri and the candy bag project. The boys were positioned as ***testers*** together with Mrs. Stasik monitoring. They were in the process of testing their candy bag until one of the handles broke (see elaborated transcript):

[BAG FAILS; ONE HANDLE BREAKS; **Dimitri's** hand surges toward bag; **James** freezes for a moment.]
**Dimitri**: [after the bag breaks] Oh!
**Mrs. Stasik**: Okay, we made it to five cups before…
**James**: [high-pitched; disbelief] What?!
[**Dimitri** turns gaze down toward bag.]
**Mrs. Stasik**: [with a calm enthusiasm] It's okay!
**James**: [quickly, stilted] I know, I'm just| cause the last time, we got like six|
**Mrs. Stasik**: What was| what did we get? What was the weight? [repeating quietly, shaking her head] It's okay.
**James**: [gesturing enthusiastically] But, wait, wait! We still have another handle.
**Mrs. Stasik**: How did it break last time?
[**James** points to **Dimitri's** hand holding the intact bag handle.]
[**Dimitri** gaze, wide-eyed, toward **Mrs. Stasik** as she speaks.]
[**James** prods the intact handle taut in **Dimitri's** hand repeatedly with his index finger.]
**James**: [high-pitched] But we still have another handle!

Here, James engaged in reflecting on and challenging the design failure by acting as a ***test evaluator*** and ***questioner***. First, James's surprise was supported by his reflection to their previous iteration of their bag that carried "like six [cups]" of candy. Moments later, James noticed and touched the unbroken handle and implied that testing should continue. This reasoning was not taken up by the teachers who deemed testing to be over when a design flaw became present, though James still brought it up. This may be because in the previous session, James made an observation and commented on another group's test, "Their [handle] already broke, why do they keep [testing]?" Previously, groups were allowed to test their bags if a working handle remained, so it made sense that James would inquire in this session about why his group was not able to continue testing with one functioning handle. In both episodes, testing spurred students to engage in reflection and reasoning in defense of their design and its failure.

## Discussion

In this study we sought to explore the nuanced responses and positions of learners and teachers to structural design failure. Four types of post-failure design actions followed by mediation from students and teachers emerged across the data set (Figure 5). In response to structural design failure, 26 positions of students and teachers were identified (Appendix).

### *Mediation of Responses to Design Failure*

The discipline of engineering constructs design failure as a normative and even serendipitous opportunity for improvement (Lottero-Perdue, 2016; Petroski, 2012). Despite this, design failure in this elementary Engineering Club was frequently interpreted negatively by students who experienced it. This resulted especially when the design failure occurred in a more public (e.g., whole-group) setting and/or when outcomes were perceived by children as competitions. Similar to other studies (e.g., Lottero-Perdue, 2015), students often took up negatively oriented failure positions when competition and "correctness" became the focus, rather than improvement, planning, and using background knowledge involved in creating functional designs. In this study, negative emotions involved frustration, confusion, disbelief, panic, and/or defensiveness when students' expectations about their design were subverted through failure.

It is possible that the focus on the EDP from Engineering is Elementary (a kind of design–build–test model, see Purzer et al., 2021, pp. 29–32) contributed to positioning students to perceive testing-related design failures in a negative light, particularly as time constraints often limited the essential redesign phase of the model. Purzer and colleagues found that 75% of engineering lessons in the elementary grades focus on a design–build–test framework (p. 32) and posited that engineering inquiries should include other types of lessons beyond the design–build–test model such as: optimization, engineering analysis, reverse engineering, and user-centered design (Purzer et al., 2021, p. 32). Thus, multifaceted portraits of engineering and nuanced approaches to pedagogy are needed. Nuanced views, such as the honeycomb framework detailed in Purzer et al. (2021), that are inclusive of many different engineering practices and stages in a dynamic framework may also support teachers and children to reposition their responses to design failure.

Furthermore, the use of a design–build–test model without multiple iterations of redesigning and re-testing (e.g., Andrews, 2016; Johnson et al., 2021) may serve to reify existing conceptions of failure in school settings rather than helping students reframe failure, especially design failure, in engineering contexts as "normative." In these negative circumstances, teacher mediation was critical to harnessing the power of these emotions within such displacement positions brought about by design failure. Mrs. Erickson, Mrs. Stasik, and Mrs. Weber found teachable moments, shifting the energy from negativity toward productive engagement.

The teachers in this study responded in similar ways to teachers in other studies (e.g., Lottero-Perdue, 2015; Lottero-Perdue & Parry, 2015). Johnson (2016) referred to teachers who engaged students in mediation after design failure as "strategic partners" because they helped students figure out potential next steps they could take to improve or redesign. Teachers who attempted to guide students by discussing possible design improvements as well as by making connections between designs and other sources of knowledge (e.g., scientific, other students' designs, prior experiences) were considered to be providing specific interventions for supporting design failure positively and productively (Lottero-Perdue, 2015). Likewise, the teachers in this study modeled the discursive interactions that engineers might use when experiencing design failure. In doing so, the teachers were *repositioning* students' orientations and mediating their responses toward design failure, thus opening up potential opportunities for learning.

### *Expanding Understandings of Responses to Design Failure through (Re)Positioning*

We found Positioning Theory to be a generative theoretical lens in analyzing how design failures are experienced and responded to during phases of the EDP. Competitive or public "high-stakes" (Johnson, 2019, p. 116; Johnson et al., 2021) design testing seems to increase emotional stakes for children. When design failure occurred publicly and competitively, it often resulted in negative responses to design failure. This also may relate to the dichotomous nature of testing. That is, the very nature of the testing positioned students' designs to either "fail" or "succeed." Competitiveness occasionally occurred within power struggles in groups. When students struggled over contributions to design ideas and who was the *builder* or *tester*, design failure responses seemed more negatively constructed and associated with more passive positions such as *forced observer* or *disengaged participant*. Furthermore, blame was often assigned as children positioned themselves in response to negatively perceived design failures.

Similar to Johnson (2019) and Johnson et al. (2021), lower-stakes design failures were also identified. These low-stakes design failures occurred during informal testing at groups' tables (e.g., wheel fell off while Dimitri wound the rubber band onto axles with Ben). Intentional failure was a planned outcome (e.g., the first iteration of the candy bag project where all bags were tested until handle failure; Johnson, 2019). In these instances, design failure was perceived as procedural and normative. It was an authentic part of the EDP, and there was space for design failure responses to be constructed with multiple positions rather than just across a binary. Johnson (2016) and Johnson et al. (2021) explore the influences on design failure associated with the EDP such as: stakes, intentionality, and referents (i.e., design requirements). Within our findings, we came to view these low-stakes design failures as authentic repositionings that supported more generative responses to design failure, such as when Saabira and James collaborated to resolve the issue with the wheel and axle of their car or when Aiden reflected on how his group's pedestal did not meet design requirements. This suggests that the epistemic engineering practice of learning and persisting through design failure is linked with positions related to innovation, creativity, and collaboration (Cunningham & Kelly, 2017).

In this study, the analysis of the multimodal interactions revealed numerous ways that children (re)positioned themselves and others within design failure episodes with regard to materials and artifacts. Certain positions tended to be exemplified by their multimodal and material-oriented nature rather than through the modality of talk alone. For example, *observer* manifested via gaze and proxemics and *idea-sharer* via gesture, talk, and drawings. *Tinkerer*, *builder*, *materials-gatherer* primarily arose through interaction with materials. Across design failure episodes, 26 different position types surfaced when analyzed multimodally (Appendix). While some of these (e.g., *forced observer*, *disengaged participant*) were clearly not optimal for learning, other positions (e.g., *idea-elicitor*, *idea-sharer*, *problem-identifier*, *tinkerer*) raise the potential for learning from and with others through a variety of modalities and meaning-making interactions linked to positions. Future studies might also be developed to derive further connections between such positions and epistemic practices of engineering (Cunningham & Kelly, 2017).

In sum, findings in this study have much in common with comparable research studies on design failure in engineering with similar participants, methodology, and aims. While studies pertaining to constructing the phenomena of design failure in elementary engineering settings are still emerging, this study's findings demonstrate rich potential and need for further explorations of how children and teachers position themselves within their responses to design failure, especially when considering the range of modalities used to accomplish those positionings.

### *Implications*

If educators are to introduce ways of approaching design failure as normative and informative, they must attend to the complexities of success and the implications of failure in general. When attempting to create complex and multi-solution problem spaces, it is not enough to simply recast the meaning of the word failure. A cultural shift in understanding and learning through the phenomenon of design failure in engineering requires creating a context, whether in formal settings (i.e., classrooms) or informal settings (e.g., afterschool clubs) with a wider range of positions and cultural norms. Such contexts require language specific to design failure to assist children and teachers thinking through types and causes of design failures (Johnson, 2019; Johnson et al., 2021) and attention to positioning. While the Engineering Club lessons and activities attempted to reposition responses to design failure, and while teachers helped provide strategic support to students when designs failed, additional explicit discourse and interactions identifying types and causes of design failures (Johnson, 2016) would have been beneficial to students and to teachers.

Curriculum and instructional design are critical toward any effort to reposition students' and teachers' responses to the phenomenon of design failure. First, if the goal is for design failure to be viewed as feedback for design improvement rather than negative feedback reflecting a lack of success, teachers need to explicitly model discursive interactions that engineers enact when experiencing design failure and when redesign is necessary. This relates to Lottero-Perdue and Parry's (2017a) notion of teachers developing and maintaining a compendium of responses to address the range of design failures encountered. Additionally, curriculum and instruction must strategically include multiple iterations of create, test, and improve within a given design problem, extending beyond the tendency to stop at the "test" phase of the EDP. Furthermore, testing experiences should not always be public or competitive, nor should public, high-stakes testing be the end goal of design problems. Instead, information learned during informal tests and tinkering during the create and testing phases should be viewed as feedback for making adjustments and improvements to students' designs. Importantly, the design problem and associated activity overall should leave enough time for students to grapple with design failure (i.e., teachers must intentionally build in time for design failure and its range of responses and for strategically repositioning students).

The domains of engineering and science provide a rich landscape for language learning and multimodal engagement (Grapin, 2019; Lee et al., 2019; Silvestri et al., 2021) wherein learners of all backgrounds can engage in discipline-specific literacy practices (Wilson-Lopez, et al., 2017). While there are some long-standing, notable exceptions (e.g., Roth, 1996, 2001), few studies have yet to investigate the full range of multimodal communicative practices used by children during engineering activities. Similarly, explorations of engineering through a multimodal Positioning Theory lens are scant, although Lönngren (2021) and McVee et al. (2021) illustrated the methodological merits of combining these frameworks to produce generative insights about engineering contexts. In the present study, findings also reveal the analytic power of a multimodal approach to Positioning Theory as a productive theoretical lens in engineering and science (Varelas et al., in press). In sum, Positioning Theory and multimodality are frameworks that can clearly be useful in future engineering research.

### *Limitations*

There are a number of limitations in this study. First, the goal of this Engineering Club was to generate interest in engineering, and as such, the club did not explicitly focus on design failure. Projects in the Engineering Club predominantly focused on lessons that Purzer et al. (2021) have characterized as design–build–test, and as such, students did not consistently have the opportunity to iterate after design failure. Design–build–test approaches may inadvertently influence children's perceptions of design failure as negative despite being in an engineering design context where design failure should be consistently framed as part of normative design processes. Additionally, this study describes only one set of students and teachers over one eight-week afterschool series of Engineering Clubs. In contrast, Lottero-Perdue and Parry (2017a) studied the same teachers for two years during the school day. Future analysis could provide instructive examples for teachers' toolkits regarding positionings within responses to design failure and the range of design failure expected during any particular project.

## Conclusion

This study demonstrates that children and teachers productively engage in an array of (re)positioning responses during engineering activities, particularly with respect to the phenomenon of structural design failure. Children take up multiple positions throughout unfolding episodes of design failure. When design failure is situated as part of the EDP, rather than a competition to be won, affordances for learning opportunities expand because children and/or teachers can engage in additional positions (e.g., *idea-sharer*, *problem-solver*, etc.) toward redesign. The resulting positions do not guarantee success, but the mediation of other students, teachers, materials, and communicative modalities provides greater leverage for opportunities to learn (McVee et al., in press).

Typically, in school settings, failure and success generally are viewed as dichotomous. But, when responses to design failure are viewed as temporal positions subject to change as part of the improvement process, learners may be able to more effectively embrace design failure as an opportunity for learning toward redesign. Within this article, we focused analysis on structural design failures. No doubt much could be learned through additional studies that explore how teachers and students position and reposition themselves in unfolding episodes of various other elements of engineering design.

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## Author Bios

**Katarina N. Silvestri** is an Associate Professor of Literacy at SUNY Cortland and is the Literacy Department Chair.

**Mary B. McVee** is Director of the Center for Literacy and Reading Instruction (CLaRI) and Professor of Literacy Education, University at Buffalo, SUNY.

**Lynn Shanahan** is Assistant Superintendent for Curriculum, Instruction and Technology (Amherst CSD) and UB Professor Emeritus of Literacy Education.

**Kenneth English** is the Deputy Director of the Sustainable Manufacturing and Advanced Robotic Technologies (SMART) in the School of Engineering and Applied Sciences at the University at Buffalo, SUNY.

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## Appendix

*Positioning Codes with Definitions and Examples*

**Role-based positioning in instances of failure**

**Definitions and examples of actions and positionings**

| Action | Defined | Positions | Examples |
|---|---|---|---|
| Problem-scoping* | Talk and/or actions related to a problem during the design process, either as it arises during building OR as posed by the design problem itself | Problem-identifier* One who pinpoints a problem | After the weight of the testing doll causes the pedestal structure to sink and collapse (structure design failure), Dimitri pulls back the doll quickly after it, stating "Yeah," then pointing to the structure stating, "but then it's gonna fall back even more because" and then pointing toward the bottom "nothing is supporting it on the bottom." |
| | | Questioner* One who asks questions relating to the problem | At the beginning of the episode, Fatima pushes the car so it moves/slides across the table and asks herself and her groupmate Emma, "okay, so which part is the back, first of all?" |
| Ideating | Involving an idea or suggestion meant to solve a particular problem with the design | Idea-sharer One who gives suggestions, ideas | After the structural design failure of the car's wheels, Owen turns his gaze down to the car, spins the wheel with his hand once more, and states to groupmate Liam, "so pretty much, let's not do these wheels." |
| | | Idea-listener One who listens to suggestions, ideas | After Aiden, Liam, and Owen test their car on the track, they notice that it moves backwards. Mrs. Erickson then takes time to explain that they could mark where their "forward progress stops," and Aiden, Liam, and Owen are all listening to her as she describes her testing idea. |
| | | Idea-eliciter One who calls for suggestions, ideas | After Jakob and Hudson's candy bag design fails, Mrs. Erickson asks, "Wait, what do you think that you should have done?" Jakob follows up with the idea, "Maybe we should've put it, like, more at the bottom." |
| | | Idea-supporter* One who endorses a suggestion, idea | Mrs. Erickson identifies an idea about the pedestals being attached, stating "It's gonna be attached like this?" while moving two pieces together. Hudson moves closer to the pedestal "yeah" and then nods, "Yeah, yeah." Dimitri, looking at the pedestal and holding the testing doll towards his middle, "yeah it's gonna be attached like that." |
| | | Idea-revoicer* One who restates another's suggestion idea | Researcher Lynn leans towards Saabira, stating "So this side made it" while she takes the wheel/axle from in front of Saabira and pulls it closer to herself, "when you put it," Lynn pulls the wheel up so it is upright, "on this end, it made it this way?" |
| | | Director* One who guides the team into executing suggestions, ideas | As Emma and Fatima continue to improve their wheel and axle design, Emma places a piece of tape onto the wheel. Fatima peels another piece of tape off the CD wheel that just came off and directs Emma, "Don't take the other [wheel] off." |
| Building | Constructing the artifact using given materials (e.g., positioning index cards, taping index cards, adjusting materials) | Builder One who uses materials to create | Ben and Liam are laying popsicle sticks onto parallel beams made of balsa wood to construct their bridge. Liam indicates that they are likely to run out soon, brings over some more popsicle sticks, and continues building with Ben and making adjustments to their growing popsicle stick platform. |
| Working with materials* | Handling, touching, and tweaking of materials as though to get a sense of their properties and how other materials work together | Tinkerer* One who touches, plays with, or manipulates materials | While building the wheel and axle portion of the rubber-band car, James holds the foam core chassis in one hand and is wiggling the CD wheel back and forth between index finger and thumb, pinched. James slides the CD wheel along the pencil axle until it hits the tape barrier that Saabira taped earlier, sliding the axle out of the curler bushing. |
| | | Materials-gatherer* One who collects materials for use | As James identifies a problem with the wheels and axles, he begins collecting pencils from around the table, stating "I don't think we have enough pencils to fit another wheel here." |
| Helping | Assisting in constructing the artifact by performing ancillary (but necessary) tasks supporting the builder (e.g., ripping tape) | Active helper One who provides assistance | While Liam moves to tape the popsicle sticks together on the platform, James leans across the table with both hands on the bridge, one on either edge of the platform, as though to steady it. |
| | | Help requester* One who asks for the assistance they need | Jakob has been twisting the rubber band attached to the wheel and axle while Researcher Katie observes. Jakob realizes he cannot use the binder clip with just one hand. Jakob moves the basket out towards Katie, the rubber-band side closest to her, and he states, "Can you like…I need someone to hold this and not…" Katie pinches the rubber band between her fingers and supports the basket with her other hand while Jakob pinches the binder clip with both hands. |

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Appendix (continued)

**Role-based positioning in instances of failure**

**Definitions and examples of actions and positionings**

| Action | Defined | Positions | Examples |
|---|---|---|---|
| Observing | Focusing gaze and attention toward the artifact | Observer<br>One who witnesses events in their surroundings | After witnessing the structural design failure (collapse) of the pedestal when tested with the testing doll, Ben leans in and gazes toward the bottom of the pedestal; his gaze remains constant on the pedestal for the rest of the episode. |
| | | Forced observer<br>One who is made to watch by another, rather than to be an active participant | After James indicates that their wheel and axle have a problem in its current design, Saabira grabs the CD wheel and pulls it out of James's hands, gaze toward the wheel. James lets go of the car and pulls his hands back towards him. Saabira pulls the car towards her using the wheel, her gaze on it. She begins taping parts of the wheel. James puts his fingertips on his face, mouth making a small O shape as he gazes at Saabira with the car. |
| Testing | Testing the artifact according to its design requirements | Tester<br>One who tries out (tests) the design | Dimitri, Fatima, and Noah are taking turns placing one-pound sand bags onto their bridges to test how much weight their bridge can hold up. They flatten the bag in their hands so it sits more securely on the bridge platform, place the bag, and then count the number that the bag represents. |
| | | Test requester*<br>One who asks for the design to be tested | After a brief power struggle over who has possession over their group's car, Owen exclaims to Liam, "Let's see if—!" and then proceeds to let the car roll on its own across the table [a test of the car's ability to roll on its current wheels]. |
| | | Test evaluator/ assessor*<br>One who comments on the results of the test | States outcomes or in-process events of the testing. In this case, student says of bridge testing in progress for Fatima, Dimitri, Noah, Liam, Ben: "Guys it's bad!" meaning the bridge will fall/break. The student has crept up to the front of the room and is looking under the bridge to assess how close it is to falling. This also includes things like "half a scoop" or "eleven bags" to show testing progress or results. |
| Improving/ redesigning* | Talk and actions that relate to making improvements on an initial design after it has demonstrated some degree of failure | Builder*<br>One who uses materials to create in order to make improvements | After Dimitri indicates the problem with their pedestal, Hudson moves a stack of index cards into the bottom section where the doll was sitting. He requests that Dimitri "put [the testing doll] back onto the pedestal. Hudson makes small straightening adjustments to pedestal before Dimitri sits the testing doll back onto the pedestal seat. |
| | | Improvement discusser*<br>One who shares ideas about ways to make the design better | After witnessing the structural design failure (collapse) of the pedestal when tested with the testing doll, Fatima offers and demonstrates an idea for improvement. Fatima takes the testing doll out of the pedestal chair, saying "No wait, we should actually, like, glue the sides" while touching the pedestal with her other hand, gesturing to the other side of the pedestal "here." After sharing this idea, Fatima states, "and then we're done." |
| | | Assessor/evaluator*<br>One who comments on the results of the test of the improved design | After a handle on Dimitri, James, and Saabira's candy bag fails, Mrs. Stasik evaluates the situation and identifies that testing can no longer continue, though they still have one working handle, stating, "Once one handle breaks…right?" Mrs. Stasik looks to Mrs. Weber to support this evaluation, and she does, stating, "Once we have a design flaw…" |
| Deconstructing the design* | Actions that relate to taking a built design apart for the purposes of either starting over or rebuilding to improve | Deconstructor/ dismantler*<br>One who takes apart a built design | After Owen shares his idea to use a different kind of wheel, Liam and Owen work together to dismantle the wheel and axle from the basket (chassis) of their car before they head back to the materials table in search of new wheels. |

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Appendix (continued)

| Role-based positioning in instances of failure | | | |
|---|---|---|---|
| **Definitions and examples of actions and positionings** | | | |
| **Action** | **Defined** | **Positions** | **Examples** |
| Disengaging* | Talk and actions that reflect disengagement with or apparent distraction from the project, particularly after a failure has occurred | Disengaged participant* One who is no longer paying attention to the task at hand | After a power struggle over the car on the testing track, James relinquishes his hold on the car to Saabira. From this point until the end of the episode, James seems disengaged. He rolls his eyes at Saabira and then begins to cast his gaze around, touch and play with the testing mat, tune into other groups who are testing their cars, and just generally putting his focus anywhere but on his own group's project. |
| Affirming* | Talk or actions that teachers use to remind students that engineers do __ (activity, action etc.). In failure episodes function to affirm children, soothe disappointment over failure etc. | Identity affirmer* One who notices and names traits of engineer identity | Mrs. Erickson: Sometimes engineers take risks; Mrs. Weber "engineers don't learn these types of things…unless they try." |
| | | Design affirmer* One who notices and names traits of one's design | Mrs. Erickson: "It was a beautiful design though," after Liam and Ben's bridge failed and Ben has a frown. |
| | | Emotional affirmer* One who notices and names emotional reactions (supportively) | Mrs. Stasik says "It's okay!" when James is visibly upset at candy bag not having greater weight-bearing capacity *after* it has been redesigned. |

*Asterisk refers to new coded positions relating to failure in this study. Silvestri et al., (2021) identified five actions and eight original positions.