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To cite this article: Amber Simpson, Andrew Osterhout, Alice Anderson, Adam V. Maltese & Jacey Ruisi (15 Oct 2024): Co-Construction of Iteration Through Failure Moments: Interactions Between Museum Educators and Visitors, Visitor Studies, DOI: 10.1080/10645578.2024.2400031

To link to this article: <https://doi.org/10.1080/10645578.2024.2400031>



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Co-Construction of Iteration Through Failure Moments: Interactions Between Museum Educators and Visitors

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ABSTRACT

Museum educators play a major role in how visitors' experience failure moments during STEM-related activities. The purpose of this study was to explore how museum educators co-constructed iteration through failure moments with visitors during an engineering activity. Utilizing an instrumental case study, we analyzed video data and one-on-one reflective meetings from five museum educators. Through our analysis, we highlight how educators and visitors are able to jointly attend, interpret, and respond to failures that leads to continuous improvements of the prototype and/or design process (i.e., iteration). The significance of this study lies in providing informal educators with approaches they can incorporate to support visitors during the failure-learning process, namely, strategies that develop visitors' noticing skills around failure.

ARTICLE HISTORY

Received 7 August 2023
Revised 3 August 2024
Accepted 30 August 2024

KEYWORDS

Failure; iteration; museum educators; noticing skills

Introduction

Prior research indicates how failure plays an important role in learning for those engaging in science, technology, engineering, and mathematics (STEM) design activities (e.g., Chen, 2021; Simpson & Maltese, 2017). Specifically, experiences with failure may activate prior knowledge (Kapur, 2014), promote creativity (Stretch & Roehrig, 2021) and problem-solving (Gomoll et al., 2018; Jackson et al., 2021), and develop risk-taking behaviors (Simpson & Maltese, 2017). These outcomes are more likely to occur in environments where guidance through failure experiences is provided from educators and/or peers (Jackson et al., 2021; Kapur, 2016; Loibl & Rummel, 2014), as well as when learners' exhibit positive reactions to failures (Loibl & Leuders, 2019; Loibl & Rummel, 2014). Researchers also acknowledge the negative reactions and emotions that people experience and express when experiencing failures, such as not asking for help (Akatugba & Wallace, 2009), diminishing interest in STEM topics (Todd & Zvoch, 2019), and developing self-conscious emotions such as shame and embarrassment (Sagar & Stoeber, 2009; Tangney, 2002).

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 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/10645578.2024.2400031>.

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Within learning spaces where making and tinkering occur, failure, iteration and change are likely, especially when creating something novel or asking learners to set their own goals and outcome expectations (Maltese et al., 2018; Ryoo et al., 2015; San Juan & Murai, 2022; Searle et al., 2018). Iteration is an expected practice for individuals who work in a STEM field (Crismond & Adams, 2012; Simpson & Maltese, 2017). As described by approximately 35 professionals who work in STEM, iteration—and persistence and tenacity—are skills and practices required to push through failure experiences encountered in their jobs (Simpson & Maltese, 2017). In addition, iteration is associated with an understanding of concepts (Rittle-Johnson & Koedinger, 2009), promotion of twenty first century skills such as critical thinking and creativity (Suh et al., 2017), and outperforming individuals who do not iterate (Marks & Chase, 2019). Iteration may also lead to more positive reactions and emotions toward failure (Marks & Chase, 2019; Ryoo et al., 2015). For instance, in a study with 5th and 6th grade students, Marks and Chase (2019) expressed how teaching the practice of iteration supported students in a desire to engage in more iterations and to report more positive affective reactions and fewer negative emotions to experiences with failure as compared to students who did not receive principles of the iterative prototyping process.

As Martinez and Stager (2013) argued, learning through iteration is not the same as failure: “any iterative design cycle is about continuous improvement, keeping what works, and dealing with what doesn’t. This is learning, not failure” (p. 70). While we agree that learning through iteration is not synonymous with failure, we contend that iteration occurs *through failure*, and may happen within the overall design but also the smaller steps and decisions within the design process. In other words, failure informs the iterative design cycle (e.g., what did and did not work) to solve a given problem in a way that is optimal for cost-efficiency, comfort, etc. The purpose of this study was to explore how museum educators supported iteration through failure moments with visitors during an open-ended engineering activity. We addressed the following research question: *How do museum educators co-construct iteration through failure moments with youth, adults, and families during an engineering activity?* The study focused on how informal educators navigated failure moments to support visitors in achieving a more positive outcome (e.g., success) through multiple iterations; similar to what DeLiema (2017) referred to as collaborative failure storytelling. In this paper, we argue that iteration can be co-constructed through an interplay of noticing skills around failure by educators, children, and adults. Individuals are able to collectively attend, interpret, and respond to failures in ways that lead to continuous improvements of the prototype and design process through iteration. This argument is significant in that few studies have explored the interactions between visitors, including children, adults and families, and museum educators with respect to visitors’ failure moments. Such educators provide a unique and generally emotionally-safe environment for visitors to fail and react positively to experiences with failure (Andre et al., 2017; Mortensen & Younas, 2024).

Relevant literature

Although we define failure as not meeting some expectation or goal set forth by self and/or others (e.g., educators), we acknowledge the term failure is defined and

conceptualized differently across STEM fields and contexts (Jackson et al., 2021). For example, Gomoll et al. (2018) conceptualized constructive failure as times when “students experience frustration and uncertainty, receive support from instructors and/or peers as they work through this frustration, and move forward in a collaborative design process” (p. 91). Gomoll and colleagues described such failure moments as short-term and accumulate to build a base for long-term success. Alternatively, Feigenbaum (2021) distinguished between generative failure and stigmatized failures. Generative failures are process-driven failures, framed within a natural and formative process. Stigmatized failures, on the other hand, are product- and grade-driven, grounded in judgments, evaluations, and consequences.

Scholars and educators may also use alternative language such as mistakes, errors, or uncertainties (Simpson et al., 2020). Chen (2021), for example, used *uncertainty*, defined as the “psychological disposition accompanying the dubiety, ambiguity, confusion, curiosity, wonder, and struggle about how to unfold, respond to, and interpret encountered situations” (p. 384). *Struggle* is also a common term associated with failure moments (Simpson et al., 2020). For instance, Warshauer (2014) grounded their examination of student struggles within mathematical activities as productive struggle or the work that learners do to make sense of a math problem in which a solution is not immediately known. Next, we highlight literature relevant to this study, namely, educators’ responses to failure and struggle within STEM learning contexts and iteration as embedded in making and tinkering activities.

Research on educators’ responses to learners’ failure moments within STEM contexts are often framed as failure-positive as they are aimed at transforming potential negative experiences (e.g., frustration, quitting) into positive outcomes and experiences (e.g., San Juan & Murai, 2022). As found by multiple researchers, these approaches included framing failure as a norm, celebrating failures, acknowledging and exploring failure moments with another, offering encouragement and choices on how to proceed, observing the approach and design of others, supporting self-regulation and reflection, probing for children’s thinking about the failure, and attending to children’s emotions (Chen, 2021; Gomoll et al., 2018; Lottero-Perdue & Parry, 2017a; Maltese et al., 2018; San Juan & Murai, 2022; Tissenbaum, 2020; Warshauer, 2014; Whittle et al., 2020). In a study by Ryoo et al. (2015), educators shared their own “glorious goofs” and challenges experienced in making and tinkering projects. These were often physically displayed on a poster for others to see, which encouraged high school girls to reframe failures as frustrations as opposed to an indication of their aptitude. Conversely, researchers also identified approaches that are less productive for children when they experience failure, namely when educators take ownership of the child’s object and try to fix issues without dialog and providing direct instructions or a single suggestion in how best to proceed (Simpson et al., 2019; Warshauer, 2014). These approaches, which may be perceived as failure-positive by educators, could result in children not learning from the opportunity or feeling incapable of making progress on the task or prototype.

As such, these approaches to failure moments are situated within the complex and multiple actions taken to support learners in how they work through their failures (e.g., DeLiema et al., 2024). Within the professional noticing of failure framework, such actions are described as responding, but are also informed by what educators notice about the failure (i.e., attend) and why the failure occurred (i.e., interpret)

(Simpson et al., 2019). Prior research highlights the importance of interpretation in being reflective about how one responds, which counters simply seeing and taking unjustified actions (Barnhart & van Es, 2015; Simpson et al., 2019). Similarly, in other frameworks, such as that developed by DeLiema (2017) within math tutoring homework sessions, the actions are described as implementing an intervention to overcome an identified obstacle and reasoning or causes of the obstacle. This process was often co-constructed as a dyad—tutor and learner.

Theoretical grounding

This study is informed by three key tenets from social constructivism: (a) cognitive development of learners is informed and shaped within social interactions, (b) knowledge construction is supported with the guided participation of a knowledgeable other (e.g., parent, educator), and (c) language and tools mediate the experience and the opportunities afforded to learners through collective and reciprocal dialogue (e.g., Rogoff et al., 1993; Vygotsky, 1978). In this study, these three tenets informed our analysis as demonstrated through co-constructing meaning and knowing through dialogue with an informal educator (i.e., knowledgeable individual) when experiencing failure in an engineering activity. As stated by König (2009), “Interaction is the key to co-construction and the starting point for processes,” negotiations, and shared thinking to “solve a problem, clarify a concept, evaluate activities, or extend a narrative” (p. 53). We further draw upon Dewey’s (1933) notion of playing with ideas and the social dimension of idea generation that are coauthored and co-constructed by individuals and through group negotiations and processes. In this case, ideas serve as a mediator through which meaning and knowing becomes internalized and part of a learner’s thinking.

Methods

This study is an instrumental case study of five museum educators engaged in an engineering activity with visitors (Stake, 1995). The selected cases are instrumental in understanding and illuminating a complex learning situation—negotiating continuous improvements (or not) when experiencing failure within a particular activity. Self-identified demographic information can be found in Table 1.

Context

The data for this study were collected as part of a drop-in engineering exhibit at a science museum located in the western United States. The museum is located in a community with a diverse population; 31% of individuals identify as Hispanic or Latine. It also has a large population of Vietnamese immigrants. Broadly, the museum’s pedagogical approach encourages visitors to engage in hands-on creative problem-solving using technology and an innovator mindset. The engineering challenge in this study involved using a variety of building materials to create devices that would launch a ball up one of the platforms on a testing “rig” (see Figure 1). The activity was designed to encourage open-ended exploration and iteration. Failure moments in this activity

Table 1. Five museum educator's self-identified demographic information.

Pseudonym	Gender	Ethnicity	Age	Years of experience at museum
Alicia	Female	European descent	31	9 years
Callie	Female	European descent	25	2 months
Mike	Male	European descent	46	6 years
Nori	Non-binary	Asian/Pacific Islander descent	22	1 year
Sonya	Female	European descent	27	4 years

**Figure 1.** Images of the exhibit.

occurred when the prototype did not launch a ball to a certain point on a wall as expected by the shooter. For example, one child launched a ball successfully into the first or lowest platform, but continued to iterate their design as they were aiming for the last or highest platform on the testing rig.

Using a case study design allows for provision of a rich description of the physical situation to provide the reader with a sense of being present (Stake, 1995). We were not present during data collection; therefore, we present the perspective of the experience from a family unit and recount the experience from one family observed through a short video clip.

As the family entered the exhibit, they were told to head to an empty blue table where they would find a toolkit of supplies that would be used in the design challenge. As they walked to the other side of the exhibit, the family passed a wall of building materials with what looked like wooden boards and large white cylinders. On the other side was a large structure that mirrored a mountain with a river flowing down the middle. As the family arrived at the table, they were greeted by a museum educator wearing a hard hat. They were told that their challenge was to create a prototype or device, like a slingshot or a cannon, that would shoot a ball into one of the platforms at the testing table. As they constructed the prototype, a museum educator stopped by to check in on their progress and offer suggestions. Otherwise, the family was left alone until it was time to test their slingshot. They were given hard hats and safety glasses during the testing phase. For the first test, the ball bounced off the platform. The museum educator stated, “So we got some good forward motion. What would you change to help it go a bit higher?” The family replied, “Maybe the aim.” On the second attempt, they pulled the slingshot down as opposed to pulling it more horizontally, and the ball went in. Cheers! The museum educator told the family, “Awesome, well done! You pulled it down a little bit more, and you aimed it a little higher. And there we go!”

Data collection

Data included one-hour videos of each educator interacting with visitors (i.e., children only, adults only, families) in the exhibit. On average, educators were observed interacting with five groups of visitors during the span of one hour. Time spent with visitors varied for various reasons such as the number of tests until a successful launch, number of tests until visitors decide to make a change, choice to move on to another exhibit, etc. A tablet was set up approximately 30 feet from the testing rig, which was the focal point of the video collection since failures were expected to happen during the launches. Educators wore a Bluetooth lapel microphone to capture audio.

An additional source of data came from individual meetings that each educator had with their supervisor to reflect on their actions (Schön, 1983). The goal of these meetings was to utilize moments from each educator's video to discuss and reflect upon the effectiveness of certain pedagogical moves when a visitor experienced a failure. The supervisor posed such questions as (a) Tell me in your own words, where do you see the failure happening with this clip? (b) What made this moment effective? (c) Where did you see ineffective facilitation around failure happening in that clip? These virtual meetings were video-recorded and transcribed verbatim. These meetings lasted approximately 25 min.

Data analysis

Data analysis began with the first author watching each video and selecting moments when failures occurred at the testing rig (i.e., the ball did not go into one of the platforms as intended by the shooter). These failure moments were compiled into a sequence of failures experienced by one youth, adult, and/or family. These moments were transcribed verbatim and included verbal and non-verbal communications such as pointing gestures and placing their hands on the prototype.

The first and second authors next engaged in an iterative analysis process guided by our prior work regarding how educators and children attend, interpret, and respond to failures during making activities (Simpson et al., 2019), as well as DeLiema's (2017) research describing responses to failure during math tutoring as constructing obstacles, blaming causes of obstacles, and intervening to resolve obstacles. We coded each educator's transcriptions individually, focusing on *how* museum educators attended, interpreted, and responded to failure moments. *Attend* refers to how failures are recognized and articulated. *Interpret* refers to the reason for the failure. *Respond* refers to verbal and/or non-verbal actions in response to the failure. We met after analyzing each educator transcript to discuss and create a codebook, which was refined with the analysis of each additional educator. After the codebook was finalized, we returned to each educator's transcriptions to re-code and discuss agreements and disagreements. Our intent was not to establish inter-rater reliability, but to collaborate and triangulate the data through our own lived experiences, expertise, and lens as researchers (Denzin, 1984). See [Online Resource 1](#) for our codebook.

The next part of our analysis focused on how iteration was co-constructed between and among individuals after each failure moment, as well as across failure moments. Co-construction, within the context of this study and analysis, is defined as museum

educators and visitors negotiating and mutually attending, interpreting, and responding to failures that lead to improvements of the prototype and/or process (i.e., iteration). To begin to make sense of how iteration through failure moments was co-constructed, we examined line-by-line interactions between educators and visitors; how statements were taken up and/or built upon (or not), how they adopted and adapted one another's language, and how statements of attend, interpret, and respond informed one another (see Figure 2 for an example).

As exemplified in Figure 2, Author 1 made such connections through arrows not only within tests but across tests, as well as between educator and adult. Row 56 in Figure 2 also highlights how the analysis focused on shared language, as well as what is taken up (e.g., "higher portion" and what was not taken up (e.g., "way closer"). Figure 2 also highlights how in Row 54, the educator built upon the adult's response in Row 51 but through interpreting the influence of the changes proposed. Next, we included memos articulating our interpretation regarding the verbal and non-verbal actions as aligned with our codes (Birks et al., 2008). Figure 3 is an example of a memo from Author 1.

As noted in Figure 3, the first two columns included who (e.g., educator, child) engaged in the actions of attending, interpreting, and responding. Further, interpretations also considered the interplay within and across tests as informed by the line-by-line analysis. This is exemplified in the analysis of the second test. For example, "goal is to get it higher, which seems to rephrase 'big motion.'" In this case the educator restated the language used by an adult in describing the projection of the ball.

	A	B	C	D
51	A		...move this higher and move this way closer (A touching design parts)	
52			Respond	
53			Describes what changes to be made that would affect the height and the arc.	
54	E		Okay. So I like that.	So by moving these higher, you can stretch it back farther, while keeping your overall structure the same.
55			Attend	Interpret
56			Agreed with ideas put forth by A.	Takes up language of A, but revoiced as to elaborate upon the impact of these changes on the prototype. So interpreting the influence of the changes. Only took up higher portion as opposed to "way closer"
57	A		And then I might move these arms some more (A gesturing wanted design movement)	
58			Respond	
59			Continues with noted changes based on recent test	

Figure 2. Example of analysis for how statements of attend, interpret, and respond informed one another.

Test 1 (Child)			
Who		Transcript	Interpretation & Codes
E	Attend	Whoa.	Defined -> cease or slow a course of action or a line of <u>thought</u> : pause to consider or reconsider —often used to express a strong reaction (Expression of failure)
		That was a lot of power.	Interpretation is focused on the ball and how it bounced off the cascade wall. External attribution on the action itself, not the prototype. (Description/Observation)
C	Interpret	I was scared to let it go.	Internal attribution; expressed an emotion - scared - regarding the test/launch (Interpret)
E		That's why we have safety gear.	Expression of failure
A	Respond	<i>Shows C how to aim design</i>	Seems this is an invitation to try again with non-verbal direction/support. Also took control of the prototype to illustrate their thinking in how to proceed (take ownership). (Hands-on support)
E		3, 2, 1, Let's go.	Statement of support/encouragement
Test 2 (Child)			
A	Attend	Whoa....	Similar language used by E. (Expression of failure)
A	Attend	A lot of big motion on that.	Similar to Line 4, focused on the projection of the ball. (Description/Observation)
E	Respond/Interpret	Let's try to get it higher so you can get it into a cascade.	Invite another attempt . Goal is to get it higher, which seems to reword "big motion". Implicitly, this was based on the test as the ball was shot horizontally and bounced off the cascade wall. Similar to above, interpretation is an external attribution based on the ball's motion. (Interpret)
E		Okay, third engineer (adult).	Statement of competence

Figure 3. Example of analysis process.

The second author followed a similar process. Next, we individually looked for common structures in how visitors co-constructed iteration (or not) through attending, interpreting, and responding to failure experiences within the activity (DeLiema, 2017; Simpson et al., 2019). We again met to discuss commonalities and differences.

Lastly, the one-on-one meetings between the educators and their supervisor served as a form of methodological triangulation (Stake, 1995). Following the complete analysis of the video data, we read the transcribed meetings for how participants discussed moments of iteration and how this aligned with our analysis (or not).

Findings

To address how museum educators co-constructed iteration (or not) with visitors as they experienced failure moments, we highlight this phenomenon within each case and included examples and quotes from one-on-one meetings as support. The examples were chosen to illustrate the common pedagogical approaches of educators that supported the co-construction of iteration (or not). Each case provided an alternative description or “reality” of the same activity as each participant had different approaches to how they supported visitors through failure moments. Cases are presented in alphabetical order by pseudonyms. In the discussion, we consider this complex learning situation across cases.

Case of Alicia

One of Alicia’s pedagogical approaches that supported the co-construction of iteration with visitors was to immediately pose a question that encouraged them to think about the test or possible changes to the prototype. The following example is from an interaction between Alicia (A) and an adult learner, Raleigh (R).

Test 2

- 1.1 A (educator): Alright, so what happened that time? [Respond]
- 1.2 R (adult): (inaudible)
- 1.3 A: It's hitting the bar? [Attend]
- 1.4 R: I'm not sure. [Interpret]

Test 3

- 1.5 R: Yeah, I think it is hitting the bar. [Attend]
- 1.6 A: You think it's hitting bar. So then what would you change for your next round of testing? [Respond]
- 1.7 R: I need to get rid of the rubber band. [Respond]
- 1.8 A: I think that's a good idea. What if you secured it maybe to these bolts? [Respond]

In this short excerpt, Alicia did not verbally interpret Raleigh's failures, but posed questions (Line 1.1 & Line 1.6) that put the onus on Raleigh to attend, interpret, and/or respond to why the ball did not land in the cascade. Initially Raleigh was unsure of the reason for the failure, but in Line 1.5, Raleigh confirmed Alicia's "hypothesized" recognition of the prior failure moment through using the same language of "hitting the bar." This highlights the co-construction of iteration through a shared language that spanned at least two failure moments, namely "it's hitting the bar." Both Alicia and Raleigh seem to know what "it" referred to through their observation of the tests as neither Alicia nor Raleigh questioned the other for clarification. In the one-on-one meeting, Alicia commented on how she asked questions such as "Okay, what happened?" or "What do you want to change?" to focus the visitor's attention on what happened and inform what happened next.

Line 1.8 highlighted another common response of Alicia, provide support and encouragement for visitors. "I think that's a good idea" was in response to Raleigh's noted change to the prototype in Line 1.7. In other words, Raleigh's response was taken up as part of the iteration process being co-constructed between the two. In Alicia's one-on-one meeting, the supervisor commented on Alicia's statements of support as they seemed to encourage visitors to make changes to their designs before testing again. Alicia also provided similar statements following a visitor's emotional response to a failed attempt by naming the adult's process as iterating. "That's okay. A lot of this is about experimentation and about what we call iteration. So building different versions of something." As expressed by Alicia in her meeting, the goal of such statements is "encouraging folks that failure is part of it and helping them stay energized with the project to move forward as opposed to like, 'Oh, it broke. We're done.'"

Case of Callie

In Callie's meeting with the supervisor, she stated, "I think my one thing that I don't do is I don't necessarily give enough time for people to figure it out on their own.

I was trying to help a little bit too much.” This was a case in which iteration was not co-constructed or supported as there was little interactions regarding what worked well, what did not work well, and/or what needed to be changed. Consider the following excerpt between Callie (C) and a child, Galen (G), who does not verbally respond to Callie.

Test 2

2.1 C (educator): Nice. Good shot. [Attend] Alright, let’s try it again. [Respond]

Test 3

2.2 C: Oops. [Attend] Try again. [Respond]

Test 4

2.3 C: Oh, almost. [Attend]

Test 5

2.4 C: Getting closer and closer. [Attend]

Test 6 and Test 7

2.5 C: Well power certainly isn’t your issue. [Interpret]

Test 8

2.6 C: Whoo. That was beautiful. [Attend] Can we repeat it? [Respond]

Callie often attended to the failures and encouraged another attempt, but she did not interpret or pose questions to elicit information that would encourage Galen to self-reflect and/or describe potential changes based on their observations of the failed tests. Further, Callie’s statements coded as respond (Lines 2.1 and 2.2) did not provide suggestions or guidance as to what changes to make, but encouraged “try again.” As implied in the excerpt, Galen rarely talked but responded through rapid testing; therefore, not making changes to the design but possibly changing how the ball was launched. But it is unclear as to whether Galen made changes based on what worked and/or what did not work. The noticing skills of attend, interpret, and respond were one-sided and did not encourage Galen to attend, interpret, and/or respond in a way that would support iteration beyond rapid testing of the prototype.

Case of Mike

One of Mike’s pedagogical approaches to failure moments was to create dissonance between what visitors expected to happen when they launched the ball and what actually happened. Through ongoing dialogue, Mike funneled the conversation to support visitors in interpreting why the ball did not land in the cascade to then build upon as they determined next steps (i.e., respond). The following excerpt exemplifies

this pedagogical approach as Mike (M) supported and co-constructed iteration with a child, Travis (T), and an adult, Rhonda (R), after Travis's ball hit the bottom part of the cascade and bounced off the wall.

Test 3 (child)

- 3.1 M (educator): Can you point really quick- where did the ball hit? [Respond]
- 3.2 T (child): Right there. (*pointing*) [Attend]
- 3.3 M: Where do you want the ball to hit? [Respond]
- 3.4 T: Uhm. Up there. (*pointing*)
- 3.5 M: Point again with your arm. Where do you want the ball to hit? [Respond]
- 3.6 T: All the way up there. (*pointing*)
- 3.7 M: Alright, watch your finger, hold it like that. Okay, so when this launches, which direction do you think it [bucket] should be pointed in?
- 3.8 T: The direction I'm pointing right now?
- 3.9 M: Uh-hum. Go ahead, fire it one more time. Let's look at where it goes. [Respond]

Test 4 (child)

- 3.10 M: Which direction is it [bucket] pointed? It's kind of pointed this way right? [Respond]
- 3.11 R (adult): I think we gotta stop it a little earlier. [Respond]
- 3.12 M: That's a possibility, what do you think?
- 3.13 T: Yeah.
- 3.14 R: Let's try it out!

As noted in this excerpt, Mike posed a question that focused the child on the test (Line 3.1). He then asked a question that highlighted Travis' goal and how the goal was different from the current result of the second testing (Lines 3.3 and 3.5). This set of questions created an awareness that the ball did not land as intended (i.e., failure). In Line 3.7 Mike began funneling Travis's interpretation of why the ball did not launch into the cascade and how to make changes to the prototype to meet Travis's goal. As such, Mike and Travis unpacked the failure moment together to then co-construct the next iteration of the design in Lines 3.10-3.14 as they continued to consider the direction of the bucket. Mike noted this pedagogical approach in his one-on-one interview: "And so I keep doing it a lot. It's like 'keep going.' I'm just like, 'Okay, look at where you're trying to go. Let's go over what you're doing.'" This excerpt also highlighted another of Mike's pedagogical approaches when supporting visitors to make sense of their failures, namely to encourage observation of the prototype or identified problem during the next test (Line 3.9). This supports the co-construction of iteration across tests. As stated by Mike in his interview, "A lot of times too, there's a bit more of like, 'Hey, watch your thing. Don't watch the ball. Watch your thing, like what does it do?'"

Additionally, we observed Mike eliciting different interpretations and/or descriptions as one interpretation was not enough, but one of multiple possibilities (Line 3.12). As another example, consider Mike's interaction with Jonah (J).

- 3.15 M (educator): When this thing launches, when it hits right here, what direction should it [bucket] be pointing? [Respond]
 3.16 J (child) *points*.
 3.17 M: And what direction is your thing pointing? [Respond]
 3.18 J *points*. [Attend]
 3.19 M: You definitely have the power. [Interpret] That ball went bing. [Attend] So what do you think we have to do to make the ball go more that way? [Respond]
 3.20 J: Bring it [bucket] back more. [Respond]
 3.21 M: That's a possibility. You want to try that?

Again, Mike framed a change in Jonah's technique as a possibility (Line 3.21). This creates the notion of iteration as continuous improvement as part of the process when experiencing failures in STEAM-related activities.

Case of Nori

Nori often provided suggestions (i.e., respond) based on what they observed (i.e., attend) and interpreted from a visitor's failure. In such instances, the visitor may not have made changes prior to testing their prototype again. This was not iteration as continual improvements based on what worked or did not work did not occur (Martinez & Stager, 2013). Similar to Callie, visitors were not part of the process of attending, interpreting, and responding. In the excerpt below, Nori (N) was engaged with two children, Heather (H) and Karri (K), and an adult, Amelia (A).

Test 3 (child)

- 4.1 N (educator): Whoa- that was really high! [Interpret] Yeah, with a lot of sling-shot designs, it's your technique that's going to determine how the ball goes. [Respond] Okay, let's do this (*K is pulling down slingshot*).

Test 4 (child)

- 4.2 N: Maybe a little softer, but higher. [Respond]

Test 5 (child)

- 4.3 N: Okay. [Attend]

Test 6 (adult)

- 4.4 N: So what are you noticing? Where's the ball hitting? [Respond] It's hitting a wall, right? [Attend] But you want it to get like, you want to get a higher but with less power, so it goes in. [Respond] Okay, let's do that. Try that (*H is pulling down slingshot*).

As exemplified in Lines 4.1 and 4.4, Nori seemed to do the thinking for the visitors they interacted with. In Line 4.4, Nori posed a question, but then quickly responded verbally to their own question, indicating that wait time may not be a common pedagogical approach for Nori. In this example the visitors were following the guidance provided by Nori as opposed to co-constructing the failure moments collectively.

Nori reflected on this group in their one-on-one meeting. Their reflection highlights how their interactions with this group focused on the technique as opposed to iteration.

I felt like my interactions weren't as effective because I think I just like let them try too many times even though I knew that it wasn't going to work the way that they had wanted. And I think instead of like, like really pushing for them to reiterate their design and then like telling them, "hey, like how can you make this more reliable? How do you make this more effective?" I think I just went with, like, "oh, it's a slingshot. And it's really about like technique of you like going up there" instead of me talking more about like their design and probing them to go back and reengineer it.

Case of Sonya

One of Sonya's common approaches to support visitors' iterations through experiences with failure was to listen and to observe the interactions between visitors, and then respond by building upon their thinking or by making changes to the prototype. This is exemplified below in Sonya's (S) interaction with two children, Zariah (Z) and Walker (W), and an adult, Brooks (B).

Test 3 (adult)

- 5.1 B (adult): The ball is too...it sticks to the thing too much. [Attend]
- 3.2 Z (child): Look Look. One more time. Now, now, untwisty. [Interpret]
- 5.3 B: Okay, do you want to fix it? Let's fix this on the spot and try again. (*looks as if tying rubber bands into knots*) Okay, do you want to try again? [Respond]
- 5.4 S (educator): So what I recommend, if you are going to use it like a really big slingshot, try to see if you can find a way to get both tethers (*points to prototype*) to be on opposite sides (*points to one side of the cup, then the other*) [Respond] because right now you have them both on one side [Attend], that's why (*makes spinning motion with finger*) it's spinning so much [Interpret].

Test 4 (child Z)

- 5.5 B: Yeah because it's spinning (*makes a spinning motion with left hand*). [Attend] We just need a stable cup. Okay, let's go back and try again. [Respond]
- 5.6 S: Now, it's okay if it does spin. So think about it, like have you ever seen a sling? So a sling would have a ball or a stone inside of it and would spin very rapidly just like this. [Respond] But it's when you release it, that's when it launches out. [Attend] So I think the problem is it's fine that it's spinning [Interpret], you just need to get it to stop. [Respond]
- 5.7 B: Yeah, not spin so much. Okay. Did you hear that? Let's go try. [Respond]

In Line 5.4, Sonya responded by providing a suggestion based on Brooks and Zariah's observations following the test. Sonya's use of "spinning so much" seems associated with Zariah's language and interpretation around "untwisty" (Line 5.2). After another test, Brooks too adopted this language of "spinning" to attend to why the ball was not successfully launching into one of the cascades. As the visitors decided to leave the testing site for a redesign of the prototype (Line 5.5), Sonya continued by providing an alternative solution to the identified issue (i.e., spinning cup)—"You just need to stop it." Brooks noted this before leaving the testing site through revoicing Sonya's design solution but continued to use the language of spin from the prior test (Line 5.7). In Line 5.4 and Line 5.6, the suggestions provided by Sonya are clearly articulated in terms of what to do, while also allowing for agency for how the visitors can undertake the suggestion. Sonya also noted this sense of agency in her one-on-one meeting. "I actually liked the comment I made there. Because they need to figure out how to make it stop. I didn't just say like, 'do this' they need to figure that out. I'm not taking away the creative process from them."

Further, this excerpt highlights how Sonya was inclined to provide suggestions and/or directions (i.e., respond) to encourage changes to the prototype, which was often taken up by visitors (e.g., Line 5.7), but Sonya rarely posed questions to elicit thinking, which may limit visitors' opportunity to engage in the co-construction process with Sonya. Consider the following example of Sonya's interaction with one adult, Yuki.

Test 1

- 5.8 S (educator): Good form. [Attend] I think we need a little more power on that.
[Respond/Interpret]

Test 2

- 5.9 S: Okay.
5.10 Y (adult): One more. One more. [Respond]

Test 3

- 5.11 S: So why don't we try replacing this. Either adding more rubber bands or replacing them with say a green rubber band that's been kind of looped in on itself, but it's stronger. [Respond] That way it has more of a snap when you release it. [Interpret]
5.12 Y *picked up prototype and walked toward workstation.*

Yuki was not asked to describe, think about, or articulate their failures but rather driven by Sonya's suggestions and directions in how to proceed. Sonya's responses were grounded in her interpretation for "a little more power" as she suggested to add rubber bands to make it stronger and "more of a snap." Sonya's supervisor noticed this as well as she provided the following guidance in their individual meeting. "Rather

than giving them a bit too much direction, like being too direct and saying, “Do this, do that, do this, rather than doing that,” like ask questions around it to spark the idea in their head instead.” Lastly, Sonya herself noted times she was “not specific enough,” (Lines 5.8 and 5.9). She framed this as encouraging but not supporting them in iteration through failure. “It doesn’t necessarily tell them how to keep trying, to hopefully be more successful.”

Discussion

The purpose of this study was to explore how five museum educators co-constructed iteration through failure moments with visitors during an engineering design challenge. Grounded in social constructivism (e.g., Rogoff et al., 1993), we argue that iteration can be co-constructed through an interplay of dialogue and noticing skills around failure by educators, children, and/or adults involved in the activity. In other words, educators and visitors are able to jointly attend, interpret, and respond to failures that leads to continuous improvements of the prototype and/or design process (i.e., iteration; Martinez & Stager, 2013). This is exemplified in Sonya’s case with Zariah, Walker, and Brooks. After Test 3, Brooks (adult) attended to the problem—the ball sticks to the thing too much. It was Zariah who interpreted the problem as something (likely a rubber band) being too twisty. Brooks responded with their next step of fixing the issue on the spot and trying again. Sonya then stepped in prior to the next test to provide additional guidance (i.e., respond) based on what she attended to (i.e., tethers on both sides) and interpreted (i.e., spinning too much).

In some cases, fostering these noticing skills was consistent with failure-positive pedagogical moves (San Juan & Murai, 2022) such as celebrating failures (Maltese et al., 2018), exploring failure moments with one another (Lottero-Perdue & Parry, 2017a), offering choices on how to proceed (Lottero-Perdue & Parry, 2017a; Maltese et al., 2018), supporting reflection (Jackson et al., n.d.), and probing for children’s thinking about the failure (Warshauer, 2014). For example, we observed Alicia asking questions that encouraged visitors to consider changes they would make to their prototype based on their testing results (e.g., Line 1.6). As another example, Sonya engaged in dialogue with visitors around failure moments, dialogue co-constructed around the failure itself (i.e., attend and interpret) and how to proceed (i.e., respond). In addition to these failure-positive pedagogical moves, one educator in this study, Mike, created moments of discord between what visitors expected to happen and what actually happened. In such cases, children were noticing why their prototype failed to meet their expectations of launching the ball into one of the platforms on the testing rig. Based on our review of prior research, this appears to be a novel approach to supporting not only iteration among visitors, but to support children and adults in engaging in professional noticing of failure moments. We identify this failure-positive pedagogical move as *playfail* (playful+failure) dissonance. Similar to other research regarding dissonance (e.g., didactic dissonance (Vangsnes et al., 2012); instructional dissonance (Evans & Cleghorn, 2022); cognitive dissonance (Socratous & Ioannou, 2018)), future research should consider the potential positive and negative impacts of *playfail* dissonance for both educators and visitors.

Alternatively, there were some cases where iteration through failure moments was minimal or there was no co-construction with visitors. In such instances, educators did not cultivate visitors' noticing skills around failure but instead did the bulk of this work themselves, such as providing too much direction and rarely posing questions that elicited visitors' thoughts on what happened, why it happened, and what to do to improve the prototype to meet the expectation of the visitors. Such unproductive moves may be explained by educators' struggling to make sense of why the failure occurred (i.e., interpret failure). In our prior research, we found interpretation of a failure moment to serve as a significant bridge between attending and responding to failure moments (Simpson et al., 2019). As stated by Barnhart and van Es (2015), "analysis [interpretation] is what gives reason to the other two skills and distinguishes them as part of effective reflection rather than simply seeing and reacting" (p. 91). Additionally, educators in this study may be uncomfortable with the word *failure* (Lottero-Perdue & Parry, 2017b) and supporting visitors' experiences with failure. In conversations with our museum partners, a notable tension regularly emerged between supporting visitors through failure while at the same time making sure they have a good experience and want to come back to the museum. Lastly, this may be explained by educators' orientations to making and tinkering within the exhibit—more commonly they are process-oriented versus product-oriented (Lemieux, 2021; Martin, 2015; Sydow et al., 2021). In cases where co-construction was limited, the dialogue seemed to focus on a successful product through rapid testing, or as stated by Nori, the technique versus the iteration process. Alternatively, these moves may be attempts at resolution where certain factors led the educator to choose the most efficient route to completion instead of a route that kept the learner in the zone of struggle (Warshauer, 2014).

Research on noticing consistently illustrates how developing noticing skills specific to a discipline or profession (e.g., professional noticing of children's mathematical thinking) takes time and is grounded in one's accumulated experiences (Jacobs et al., 2010). As stated by Goleman (1985), "The range of what we think and do is limited by what we fail to notice" (p. 24). This may account for differences between museum educators that were more likely to promote iteration through co-constructing failure moments with visitors as compared to the educators who were less likely to engage visitors in co-constructing failure moments. Similar to Dewey's (1933) notion of idea generation as a coauthored and co-constructed process, it may be the case that the ability to attend, interpret, and respond acts as a mediator through which meaning and knowledge of iteration in the external, social plane becomes an internalized process by visitors when experiencing failure moments (e.g., Rogoff et al., 1993). As such, in cultivating noticing skills in visitors, supporting them to attend, interpret, and respond during failure moments, there is the potential to support visitors in slowing down the process of iteration (e.g., DeLiema et al., 2024) and developing persistence (e.g., Simpson & Maltese, 2017).

Lastly, while not a focus of this study, watching video clips prior to one-on-one meetings allowed educators to notice their own pedagogical moves around failure, particularly moves that do or do not support iteration. This highlights the potential use of video as a viable method for museum educators to reflect on their practices. In this study, video served as a way for educators to "see" themselves as a facilitator of failure (e.g., Borko et al., 2008; Simpson, Anderson, Goeke et al., 2023a; van Es &

Sherin, 2009). Reflecting on one's practices through videos may also serve as an opportunity for educators to learn through iteration and make "continuous improvement, keeping what works, and dealing with what doesn't" (Alazmi, 2023; Martinez & Stager, 2013, p. 70; Tran et al., 2013). Further, video as a reflection tool has the potential to shift their thinking and beliefs about failure moments and their failure pedagogical moves, as well as develop a common and shared language of failure as an educational team (Simpson, Anderson, & Maltese, 2023; Tran et al., 2013). The scholarship from Ash et al. (2012) even highlights how video reflections may transform the identities of museum educators from didactic tellers to mediators of learning.

Limitations and future directions

First, this study focuses on data and experiences from one engineering activity. It was also an activity in which failure moments were apparent, namely, when the prototype (e.g., catapult, slingshot) did not launch a ball to a certain point on a wall. We propose the analysis and findings are likely transferable to similar sites that engage visitors in drop-in engineering tasks with clear indicators of success (Guba, 1981). Future research could build upon our results to consider co-construction of iteration moments within a variety of STEAM-related activities in informal environments where failure may or may not be apparent, such as paper-mâché or deconstructing an electronic toy. In such cases, failures may be less visible to the educator but reside within individual visitors' perspectives (Harrison, 2019). A further step would be to broaden the analysis of museum educator-visitor engagement around failure to include the role of social objects; material objects that become the joint focus and sense-making tool between museum educators and visitors (Kumpulainen et al., 2019).

Second, we acknowledge that the five cases in this study may not represent the full range of possible cases, particularly within the context of the engineering design challenge (Stake, 1995). We observed approaches that a few educators took when trying to support learners through failure and how this supported some visitors to iterate. Future work may consider the prevalence of such responses and behaviors, as well as consider other failure pedagogical moves not captured in our data. Similarly, educators may support visitor's differently when engaging with an adult, a child, or a family that experiences failure. From our data, we conjecture that educator's may attend, interpret, and respond differently, not so much because of the learner, but because of how adults offer up reasons for why the failure occurred and/or what changes to make to the prototype while children may wait to be asked a question or be provided direction from the educator (i.e., "playing school"). Therefore, future research could expand upon this notion and educator's failure pedagogical moves are in response to visitors' moves as opposed to taking lead as educator within the co-construction of failure moments.

Third, we did not gather data from visitors' regarding their interactions and experiences with a museum educator when experiencing moments of failure. What might visitors' view as (un)productive and unsupportive actions from educators when experiencing a failure? How might this inform professional development for museum educators' failure instructional moves? We encourage others researchers to address these questions along with us as it will be a focus of our work in the future.

Conclusion

As noted by McGuire et al. (2022), there have been few studies to examine how visitors' experiences are shaped through interactions with educators in informal learning environments. We add to this literature base through considering the joint activity or intergenerational dialogue and negotiations (Vossoughi et al., 2021) between museum educators and visitors through failure experiences within an engineering task. As part of this study, we considered how visitors co-constructed their own failure experiences through how they attended, interpreted, and responded to museum educators (Simpson et al., 2019). One significance of this study lies in providing informal educators a few strategies to invite visitors into the co-construction process, namely, strategies that support visitor's noticing skills—attend, interpret, and respond - around failure; for example, creating playful dissonance between educators and visitors where there is a shared understanding developed through verbal and non-verbal acts of communication (e.g., pointing gestures). This was often done through scaffolding visitors' interpretations of why the ball did not launch appropriately and the different possibilities to support iteration through failure moments.

Another strategy to support the co-construction of iteration with visitors is the adoption (e.g., “hitting the bar” by Alicia) and/or reframing or revoicing (e.g., untwisty to spinning by Sonya) of visitors' language as it provided a common language for museum educators and visitors to communicate with one another; it promoted a shared understanding around the iteration process as opposed to a state of confusion. The same could be said for non-verbal actions. For example, in this study, the action of pointing to where the ball hit and where the visitor wanted the ball to hit could be taken up by educators to build a shared understanding around visitor's expectations. We recognize that developing these shared understanding when experiencing failure may also be challenging, but important for educators to develop and co-construct with visitors who are non-native speakers of English.

We recommend, educators should develop questioning techniques framed at encouraging learners to *interpret* and *respond* to the results of testing a prototype, whether they are successful or not. Questions should be followed by wait time (e.g., 3-5 s; Row, 1974), which has been shown to increase children's explanations, reasoning, and engagement (Ingram & Elliott, 2016; Strickler-Eppard et al., 2019; Tofade et al., 2013), children's reduction in “I don't know” responses (Tofade et al., 2013), and shifts in the quality and variety of questions posed by educators (Tofade et al., 2013). Similarly, as suggested by Harlow and Skinner (2019), wait time may allow opportunities for educators to observe visitors engage in the exhibit to attend and interpret patterns in how they respond to failure moments before stepping in and providing guidance, or in the case stepping in and engaging the co-construction process. As such, the failure-positive strategy of questioning (and wait time) is juxtaposed to providing suggestions as to how to respond to failure moments. While suggestions seemed to support iteration, they did not support the co-construction process as visitors often took up the suggestions and were not positioned to interpret or respond to failures.

In addition, building on the use of video data as a reflection tool, the development of these strategies may inform a professional development cycle where educators select and share video clips of positive and/or negative teaching moments around failure with the goal of building one's failure-positive and failure-supportive pedagogical moves

when interacting with visitors (e.g., Amador et al., 2021; Borko et al., 2008; Simpson, Anderson, & Maltese, 2023). Reflective practice has also been used to narrow the gap between intentions and reality (e.g., Levis & Farrell, 2007). Lastly, this research continues to promote our understanding of teaching and learning through failure moments within informal learning environments; an environment that has the potential to counter the negative and debilitating views of failure in school and other settings (e.g., Martin, 2015; Simpson et al., 2018).

Acknowledgment

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Ethical approval

The study was approved by the appropriate institutional research ethics committee (Binghamton University Institutional Review Board; Approval No. STUDY00002698). We certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent were obtained from all individual participants included in the study.

Declaration of interest

The authors declare no conflict of interest.

Funding

This material is based upon work supported by the National Science Foundation under Grant No. 2005927 (Binghamton University) and Grant No. 2005860 (Indiana University).

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