Making Meaning of Design Failure

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Introduction

The design firm IDEO proclaims, "Fail often to succeed sooner" and the Stanford d.School adds "Fail early, fail often"; these mantras are often used in engineering to encourage prototyping and iteration during the solution-generation process of design (Atman, Kilgore, & McKenna, 2008; Lewis & Wright, 2012). The demands for iteration and learning while designing—implicit in these statements—are evident in secondary engineering standards and literature surrounding design. For example, the Standards for Technological Literacy, produced by the International Technology and Engineering Educators Association (ITEEA & Technology for All Americans Project, 2007) define design as "an iterative decision-making process…" (p. 237) and hold that students should understand the attributes of design (STL 8), the role of troubleshooting and experimentation (STL 10), and be able to apply the design process (STL 11). The Next Generation Science Standards for engineering design include "iterative testing and modification of a proposed object" (MS-ETS1-4) among other design standards (NGSS Lead States, 2013). Indeed, Crismond and Adams (2012, p. 750) identified "learning while designing" and "working creatively to generate design insights and solutions" as key performance aspects of design and "managed and iterative design" and "reflective design thinking" as patterns of informed design work which might be attainable by design students.

Iteration and learning through design are a key objectives of a novel, design-based curriculum we have developed (Jackson, Zhang, Kramer, & Mentzer, 2017). The robotic design lesson is part of a larger research study investigating student attitudes and motivation for engineering. However, in contrast to traditional robotics, these lessons expose students to soft robotics. Soft robots are a classification of robot design that use pliable, elastic components to achieve new forms of motion in the final design (Trimmer, 2013). While evaluating this learning material, we saw students struggle to successfully fabricate a robot and have become concerned about the impact these design failures might have on student confidence.

In light of the focus on iteration as an important attribute of design, failure would seem to be an accepted, even expected, part of design and a learning opportunity—designers iterate and revise designs because the first ones didn't work. However, cognitive misrepresentations of the design process may lead students to work step-by-step rather than in a cyclical, iterative way (Crismond & Adams, 2012). There is additional evidence that beginning design students tend not to value iterating as highly as they do with more experience (Adams & Fralick, 2010). Further design experiences are necessary so that reflection can inform the design *process*, not just the project-level work (Lawson & Dorst, 2009), and students can adopt "designerly ways of knowing" (Cross, 1982).

Yet, paradoxically, despite the significance of failure in engineering design, the experience of failure itself may be a barrier to confidence and persistence. In a previous investigation of elementary engineering experiences, Lottero-Perdue and Parry (2015), teachers reported positive and negative student responses to design failure: trying again, working as a team, and conducting more research were among productive reactions, however a greater proportion of teachers reported student frustration as a result of design failures. Drawing on social cognitive theory as a further, theoretical example (Bandura, 1977, 1986), students' previous experiences with a task are instrumental in their self-efficacy, or belief in their abilities to perform a task. Seeing initial successes or external models for success (e.g., peers or mentors) can grow confidence, encourage effort and persistence, and raise achievement (e.g., Liu, Lou, & Shih, 2014; Mamaril, Usher, Li, Economy, & Kennedy, 2016; Zimmerman, 2000). However, "repeated mishaps lower [confidence], particularly if the mishaps occur early in the course of events" (Bandura, 1977, p. 195).

Given the seeming disconnect between realities of design—iteration and failure—and motivational theories, it is important that design educators investigate how beginning designers encounter design iteration and failure and how these experiences impact fledgling engineering confidence. This paper proposes the research question, "What are K-12 student experiences of failure in the design process?" We offer a research design to investigate student experiences of failure in the design process—specifically, this research proposal is designed to address 9th grade student experiences of failure while conducting robotics design. We propose a case study approach to qualitative inquiry. This approach offers a chance to capture student voices while describing the research problem and leverage a variety of information sources to describe the learning environment (Creswell & Poth, 2017; Leydens, Moskal, & Pavelich, 2004). Finally, we propose an inductive process to uncover themes surrounding student experiences of design failure. Case studies then use these themes to produce "concrete, context-dependent knowledge" (Flyvbjerg, 2006, p. 233) which can be applied to the development of design expertise; specifically, from these themes we might draw implications from design teaching to help students navigate their experiences with failure. The present version of our paper offers a call to grow understanding of design failure experiences and a research direction, however we will include preliminary findings at the time of the CTETE conference.

Methodology

Case Study

Case study research can be described as an attempt to "develop an in-depth understanding of a single case or explore an issue or problem using the case as a specific illustration" (Creswell & Poth, 2017, p. 96). Though the research focus may seem similar to other qualitative approaches, a case study can be identified by its focus on a bounded setting which may be a given individual, event, or time and place. Though the researcher begins with a detailed description of the case, different typologies of case study serve to clarify intent (Creswell & Poth, 2017):

1. A study may be *instrumental*—seeking to understand an issue or case in depth—or *intrinsic*—where the case itself is of interest rather than the illustrated concept.
2. The study may be of a single case or involve multiple cases.
3. And the analysis may be *holistic*—where the entire case is analyzed and presented—or *embedded*—analysis and presentation are of a specific aspect of the case.

In our proposed research design, the single, instrumental case is the implementation of our soft robotics curriculum for 9th grade students in a Mid-Atlantic state. Several teachers are delivering the curriculum after participating in professional development. Given the consistency among these classrooms (e.g., they are within the same district, using the same materials) we consider this a single case; our focus of analysis is student experiences of design failure within the soft robotics implementation.

Context

Our instructional material changes are designed to be implemented in the 9th grade *Foundations of Technology* course offered by *Engineering byDesign*. The robotics build activity takes place over approximately five class meetings, using silicone rubber and fabric for construction. The research team has partnered with teachers in the district to provide teacher professional development on the lessons and evaluate the implementation. After trying a design out, the silicone construction requires students to remake the entire robot rather than tinker with one aspect of the design. While the larger study is ongoing, the implementation has been challenged by fabrication issues and a lack of build success among participating students. Though the intent is for students to iterate, the goal is for them to ultimately succeed in making a robot. But the current estimate for successful fabrication is only 54% (Zhang, Jackson, Mentzer, & Kramer, 2017). As we have heard about student and teacher experiences and visited with the classrooms, we have become increasingly concerned about the impact these design failures might have on student confidence—an outcome we are trying to increase through the overall research. We further feel the importance of trying to understand beginning designers' experience of design failure as proposed here. The prevalence of design failure and holistic iteration process in this design activity present a good opportunity for investigating the student experience.

Sampling

Sampling should support the multiplicity of perspectives, attempting to provide as much coverage as possible on the true experience of failure in design. Potential participants will be identified by criterion sampling through teacher recommendations. Participating students should have encountered failure in past design projects to some degree and will be taking part in the robotics fabrication activity where iteration is prearranged and failure is likely to be encountered at some phase of the design process. Five students will be invited to participate in the research study through the data collection methods described next.

Information Sources

Several information sources surrounding design failure will be used in this research. First, a modified version of Seidman's (2013) phenomenological interview approach will be used. Second, classroom observations and participant think-alouds will take place while students are doing the soft robot design project. And third, student design journals will be collected following the soft robot lessons.

Phenomenological interviews.

Each research participant will be interviewed based on the "phenomenologically based interviewing" approach from Seidman (2013, p. 14). This method explores the participants' experiences and the meaning they make from that experience. Seidman (2013) notes that interviewing gives the participant a chance to reconstruct and make meaning of their experiences. The original process entails three in-depth interviews on the participant's focused life history, the details of the experience, and reflection on the meaning (p. 20-22). This structure was adapted to include an abbreviated "design history" and reflection interview before and after the soft robot lessons, respectively. Observations during the design process will replace the second interview.

Classroom observations and think-alouds.

The second phase of phenomenologically based interviewing involves "concrete details of the participants' present lived experience….within the context of the social setting" (Seidman, 2013, pp. 22-23). For our study we propose to conduct classroom observations that follow-along with the students during the engineering design process. The details of this experience are used later in the reflective interview (e.g., "Given what the details are, how do you make meaning of your experience?"). Regarding the decision to conduct participant observation, Wolcott (2005) asked, "Can whatever [you] want to study be 'seen' by a participant observer at all?" and "[Are you] well positioned to observe those phenomena?" (p. 88). With the purpose of eliciting the "what" of an experience—the concrete details—participant observation is an appropriate technique to come to understand the meaning of design failure. Think-aloud protocols are common in design research (e.g., Atman, Chimka, Bursic, & Nachtmann, 1999; Daly, Yilmaz, Christian, Seifert, & Gonzalez, 2012; Dorst & Cross, 2001; Mentzer, Becker, & Sutton, 2015). The addition of verbal statements from the participant can help uncover important thoughts of the participant as they participate in the robotics build process.

Student design journals.

Throughout the design process, students are required to keep a design journal that documents their work: research, decision-making, experimentation, and evolution of the product. This information will support the detailed account of the experience and add to the meaning of design failures for students. Students typically have flexibility in how they record this individual record, however specific several questions will be developed and included to ensure that students step back to reflect on the meaning of their experiences with design failure.

Data Analysis and Interpretation

In general, inductive qualitative approaches tend to move from narrow to broad, from the data—interviews, observations, and documents—to codes and themes. For this case study analysis, we will follow such an inductive process informed by the inductive analysis process of Hatch (2002). Analysis will begin by reading the information sources holistically, especially noting comments related to failure, iteration, revision, or other synonymous words. By reading the data and looking for patterns and relationships, codes can be identified which contain the salient messages of participants. This process is iterative and Hatch (2002) notes that researchers may go back in order to refine the codes or domains (groups of codes) used. After foundational elements are identified and coded in the data, broad, interpretive themes will be considered. Themes are the "connecting threads and patterns among the excerpts [of the information sources]" (Seidman, 2013, p. 127) or "broad elements that bring the pieces together" (Hatch, 2002, p. 173) or "broad units of information…to form a common idea" (Creswell & Poth, 2017, p. 328).

A pattern for case study reporting given by Creswell and Poth (2017) also steps from the details of the case to broad interpretations. These planned data collection and analysis procedures will enable us to report on the case context and content in detail. Next, each emergent case theme will be discussed and substantiated by evidence from the student experience such as quotes, observational notes, or segments of student work from the design notebook. Finally, lessons learned from the case will be reported; these are also called assertions, patterns, or explanations (Creswell & Poth, 2017, p. 98) and are generalizations from the research which might be applied in different contexts.

Validity, Reliability, and Trustworthiness

Creswell and Poth (2017, p. 259) recommend choosing at least two strategies for validity in research. These planned aspects of the research might be seen as guidelines to produce high quality scholarship and a "credible report…that readers feel trustworthy enough to act on and make decisions in line with" (Tracy, 2010, pp. 842-843). First, **triangulation**, using multiple conceptual "angles" to support conclusion, is demonstrated by using multiple information sources to understand the case (Merriam, 1995, p. 56). Second, we plan to represent the case and student experiences with design failure through **"thick description"** (Merriam, 1995, p. 58). Thick description entails providing detailed explanations of the situation, especially in the participants' language, so that readers can come to reach the same conclusions through the research report.

Conclusion

There is an "inherent paradox" of choosing a research topic: it is something we are passionate about yet we are supposed to remain "open to the process of listening and careful explanation…approach[ing] [our] research interests with a certain sense of naiveté, innocence, and absence of prejudgments" (Seidman, 2013, p. 36). If we hope to foster student design identities, we must experience the paradoxes and tensions of design as they do: we must understand how K-12 students experience the challenge of design failure and the insistence to learn from it. Our proposed study context is helpful for investigating this question since it is reasonably expected students will fail and iterate in their soft robot designs—it is prefigured into the curriculum experience and has been seen in previous implementation attempts. Since design failure and iteration is faced in real-world practice by designers and engineers, it is important that students face these experiences in their development of such identities. Yet, strategies for helping students navigate encounters with design failure may be obtained by a closer look at these experiences.

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