“Things Are Made to Fail”: Constructive Failures in a Middle School Robotics Curriculum

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Abstract: Framing failure as constructive can help students engage in design practices. This case study examines the role of failure in a middle school human-centered robotics curriculum. *Constructive failures* are scaffolded failures that build a base for solving engineering design problems. This research explores constructive failure as an asset for learning through iterative design and considers the role of the facilitator in providing space for and supporting constructive failure experiences.

Keywords: STEM learning, human-centered robotics, problem-based learning

Twenty-first century collaborative problem-solving skills, which include negotiating ideas, organizing the problem-solving process, and maintaining communication, are essential in the everyday work of engineering (Dym et al., 2005). Here, we explore how framing failure as constructive within an engineering design unit supported the development of these skills. This work builds on conceptualizations of productive failure and productive success (Kapur, 2016), providing examples of one instructor’s framing and scaffolding of failure to further theorize about the role of failure experiences in problem-based learning.

Constructive failures are those in which students experienced frustration and uncertainty, received support as they worked through this frustration, and were able to move forward in a collaborative design process. These supports enabled productive success, the achievement of viable solutions to complex problems (Kapur, 2016). Constructive failure is a scaffolded dimension of productive success, supporting student efforts by framing iterative trial and error as necessary. Supporting failures *throughout* a learning experience can help students by encouraging them to articulate their challenges and providing opportunities for learning in problem-based activity (Blumenfeld et al., 1991).

This research presents a problem-based human-centered robotics (HCR) unit as a context to spark learners’ interest in STEM by connecting to the social aspect of engineering design (Hamner et al., 2008). HCR centers on the design of robots that serve human needs (Schaal, 2007). This work explores how students solving an HCR problem engaged in collaborative design through the positioning and negotiation of failure experiences as they worked collaboratively to design a robot that served a need in their local environment. The curriculum engages students in engineering design cycles that involve asking questions, brainstorming solutions, collecting information, developing and testing solutions, and improving designs (Resnick, 2007). In earlier iterations of this unit, learners struggled to harness their frustration and move forward (Gomoll et al., 2016). The unit was iteratively refined to provide opportunities to navigate inevitable failures with facilitator support. We consider failures during the problem-solving process as a positive norm for learning through design (Kolodner et al., 2003).

This case study examines how framing failure supported students’ work imagining, designing, and building robots to be used in their classroom. We conjecture that by re-positioning failure as a norm, students were able to publicly test their designs and learn from their mistakes—leveraging failure as constructive.

Methods

Participants included sixteen students (ages 12-14) taking an Applied Science class in a rural U.S. public middle school. The HCR unit took place over approximately 25 class sessions with 35-50 minute sessions daily. All written artifacts were collected, each group was audio recorded, and video footage capturing the full class and several student groups was collected each day.

To understand the role of failure, we focused on two groups that navigated failures that went beyond social dynamics and progressed furthest with their designs despite early frustration. Group 1 was composed of one eighth grade female, one eighth grade male, and two seventh grade males. Group 2 was composed of two eighth grade males, one eighth grade female, and one seventh grade female. The activity of both groups was traced using Jordan and Henderson’s (1995) guidelines for interaction analysis. Across collaborative data analysis sessions, definitions of failure were refined, and themes related to the role of failure were highlighted.

Results and discussion

Across four episodes, we show how the instructor introduced and scaffolded failure as a constructive learning opportunity. Her consistent framing of failure as a norm helped students to feel supported as they failed early and often, leveraging failure as constructive in the learning process. In studying the groups' failures and how they moved forward, we better understand how failure within a PBL cycle and design experience can provide an authentic context to help learners orient to failure as a norm in collaborative engineering design. Throughout these episodes, iterative failure contributed to groups' successes as is typical in engineering design.

In our first episode, we highlight the instructor's use of metacognitive modeling early in the unit to demonstrate how students could talk themselves through inevitable challenges. Within this episode, the instructor legitimized emotional reactions to failure and presented failure as a norm in the design process. This framing helped students to become aware of and manage failure in situ. Our second episode highlights early frustration experienced by a student group as they engaged in an embodied programming experience. Here, students struggled to agree on a set of directions and did not reach a consensus. The instructor recognized this challenge and asked students why they were frustrated—validating their emotional response and helping them to move forward. At this point, the instructor noted that in the process of design, it is not expected that students can (or should) get things right the first time. This support helped the group to own and articulate future instances of constructive failure. In episode three, this same group discussed their prototype. One student stated: "It's a prototype, things are made to fail." This response appropriated the teacher's guidance on the role of failure in design. The student who made this statement used failure constructively to move his group forward and to carry out initial phases of user testing. Finally, episode four centers on a second group engaged in troubleshooting as they tested code they had written for their robot. Recognizing that the robot's wheels weren't calibrated correctly, the group used trial and error to see what programmed instruction would result in the 90-degree angle they needed to move their robot to a specific location. As the group bounced between numbers, they displayed their ability to negotiate disagreements and come to a consensus. This group demonstrated agency as they leveraged a failure experience. They did not ask for help immediately, and they embraced an iterative design cycle.

Throughout these episodes, failure functioned as a formative assessment by allowing students to test their design ideas and receive feedback—ultimately leading to productive success. For many students, particularly those who have been trained to avoid failure, early failure without support may trigger disengagement. As 21st century STEM careers require practitioners to solve problems collaboratively, manage uncertainty, and engage in design thinking, we argue that curricula and facilitation that explicitly incorporate failure experiences will better prepare students for future STEM engagement and careers. This work is a starting point for future research that explores the cultivation of collaborative problem solving and design thinking skills through formative experiences of failure.

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