Designing human-centered robots: the role of constructive failure

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ARTICLE INFO

Keywords:
Constructive failure
Collaborative problem solving
Design thinking
Problem-based learning
Human-centered robotics

ABSTRACT

Framing of failure as constructive can help students to engage in authentic practices of iterative design and to leverage failure in future experiences. In contrast to classroom norms that privilege “right” answers and perfect final submissions, classrooms that position failure and iteration as norms prepare students for the realities of complex problem solving. This qualitative case study examines the role of failure in one middle school human-centered robotics curriculum, a challenging collaborative problem-solving experience for these students. In this context, we conceptualize constructive failure as short-term and supported experiences of failure that build a base for longer-term success solving complex engineering design problems. Within this unit focused on the design and development of robots that serve a social function, scaffolds were provided to orient students to the benefits of failing fast and often. Across several episodes, we show how the instructor of this course introduced and supported failure, and we trace the trajectory of two groups as they moved from frustration to articulating failure as necessary in a comparative case study. This analysis highlights constructive failure as an asset for learning through iterative design and for the development of creative problem-solving skills. We conjecture that formative experiences of failure can support the process of problem-based learning (PBL) – particularly PBL centered on design thinking. This case study works to inform how future K-12 classrooms and curricula might be structured to support and recognize failure as a positive norm and a valued part of collaborative problem solving and design.

1. Introduction

The development of collaborative problem-solving skills is important in the rapidly changing digital age, particularly for Science, Technology, Engineering, and Math (STEM) learning (Griffin, McGaw, & Care, 2012). These 21st century problem-solving skills, which include negotiating ideas, organizing the problem-solving process, and maintaining communication, are essential in the everyday work of science and engineering (Dym, Agogino, Eris, Frey, & Leifer, 2005; Liu, von Davier, Hao, Kyllone, & Zapata-Rivera, 2015). In particular, engineering design provides a complex and ill-structured problem context that demands collaborative problem-solving skills, often among individuals with different disciplinary backgrounds and skills (Jonassen, Strobel, & Liu, 2006). Design thinking, an important aspect of engineering design, requires STEM practitioners to define a problem, navigate uncertainty, consider connections within a system, and communicate ideas to a team. Engineering design can provide opportunities for authentic experiences needed to prepare young people for the iterative nature of design work and collaborative problem solving, which is broadly applicable to many career fields (Dym et al., 2005). As students engage with engineering design challenges, they cultivate design thinking strategies in the process of proposing and testing solutions. Design-based learning experiences in particular can motivate...
students to learn and apply new STEM content, skills, and practices (Hmelo-Silver, 2004; Blumenfeld et al., 1991). Furthermore, learning through design provides challenges and uncertainties that prepare students to engage with thinking and problem-solving processes (NGSS Lead States, 2013). In U.S. schools, robotics has been integrated as a way to address new STEM standards, including those that involve collaborative problem solving and engineering design (Hamner, Lauwers, Bernstein, Nourbakhsh, & DiSalvo, 2008; NGSS Lead States, 2013). The management of uncertainty in collaborative robotics design problems can support student learning and the development of design skills (Jordan & McDaniel, 2014). Uncertainty in robotics design means that the road to success is not assured, and that there is a high likelihood of failure along the way to eventual design success (Simpson & Maltese, 2017). We build on this work – exploring how students solving a human-centered robotics (HCR) problem engaged in collaborative problem-solving practices and design through the positioning and negotiation of failure experiences. This case study provides a telling case that demonstrates how the framing of failure informed students’ design work and suggests that scaffolded failure experiences promote the development of design thinking skills and practices.

We consider constructive failures as those in which 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. These supports enable what Kapur (2016; Hmelo-Silver, Kapur, & Hamstra, in press) labeled productive success. Thus, we articulate the importance of positioning failure as a constructive activity. We consider constructive failure as a dimension of productive success – supporting student efforts and framing failure and iterative trial and error as worthwhile and necessary. In instances of constructive failure, students make visible the barriers that slowed their progress. They work in partnership with peers and facilitators to acknowledge and move past these road blocks. Scaffolding student uncertainty as a learning opportunity can help students by slowing them down, encouraging them to articulate their challenges, and providing opportunities for learning while engaging in project-oriented activity (Blumenfeld et al., 1991; Reiser, 2004; Hmelo-Silver, 2006). Building on Kapur (2016)’s notions of productive failure and productive success, we distinguish constructive failure as an extended and scaffolded experience of failure(s).

The research reported here presents a problem-based human-centered robotics (HCR) unit as a context to spark learners’ engagement in STEM by connecting to the social aspect of engineering design (Hamner et al., 2008; Baker & Leary, 1995; Weinberg et al., 2007). We conjecture that formative experiences of failure can help students to engage in authentic practices of iterative design and collaborative problem-solving and to leverage failure constructively for future engineering and design work. As students experience low stakes and recurring failures, orient to them as a norm, and determine how to move forward, they have opportunities to learn about and through design (Kolodner et al., 2003).

Throughout the HCR unit and comparative case study featured here, students were supported in their collaborative problem solving as they asked questions, collected information, developed and tested solutions, and improved their robotics designs. In earlier enactments of this unit, learners often struggled to harness their frustration and move forward (Gomoll et al., 2016). To address this challenge, the inquiry-based curriculum was iteratively refined to provide opportunities for students to experience frustration and failure throughout the unit, with facilitator guidance in place to support students. As Brophy, Klein, Portsmore, and Rogers (2008) argue, “activities of design, analysis, and troubleshooting are what engineers do to develop new devices...processes...and infrastructure...and [to] change existing ones that shape our lives” (p. 371). With this in mind, the HCR curriculum engages students in iterative design cycles (see Fig. 1).

In the following sections, we position opportunities and norms centered around failure as a means of managing inevitable uncertainties and frustrations in engineering design. We consider failures throughout the problem-solving process as a positive norm for learning through design. Throughout our discourse analysis, we take deep dives into interactional episodes – exploring how two student groups navigated failure throughout an engineering design unit.

![Fig. 1. Engineering design cycle (adapted from Resnick, 2007; Gomoll et al., 2016; Gomoll, Šabanović et al., 2017; Gomoll, Hmelo-Silver et al., 2017).](image-url)
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