

Problem-Solving or Solved Problems: Constricting Design Challenges in High-School Engineering Education to Avoid (Disruptive) Failures

Yasmine Belghith, Julia Kim, Meltem Alemdar, Roxanne Moore, Jeffrey Rosen, Mark Riedl, Jessica Roberts
byasmine@gatech.edu, julia.kim@gatech.edu, meltem.alemdar@gatech.edu, roxanne.moore@gatech.edu,
jrosen3@gatech.edu, riedl@gatech.edu, jessica.roberts@gatech.edu
Georgia Institute of Technology

Abstract: We investigate how high-school engineering teachers anticipate and deal with disruptive and productive failures in students' design challenges. This study involved a six-week participatory design process with two teachers, revealing that teachers often make design challenges too prescriptive in order to prevent disruptive failures, which can hinder opportunities for productive failures. We discuss the implications of failure mitigation and suggest opportunities to better support teachers, including the design of an intelligent system.

Introduction

High school engineering courses provide students with hands-on, open-ended design challenges that require the application of various learning objectives such as practicing the Engineering Design Process (EDP) and iterating on their prototypes, which can lead to both productive and disruptive failures. *Productive failures* (Kapur 2008) force students to revisit their documentation and engineering knowledge to engage more deeply with the problem, and though they may cause deviations from the original curriculum plan, they are beneficial to the overall learning. On the other hand, some deviations from the teacher's plan may not have pedagogical value, such as students ignoring the tasks at hand. We refer to those deviations as *disruptive failures*. These dimensions lead to a significant cognitive and pedagogical load for teachers in planning and executing design challenges. This paper aims to investigate the following questions: (1) What disruptive and productive failures are high-school engineering teachers anticipating that students will face in solving design challenges? (2) How are they actively trying to prevent and help students recover from disruptive failures, specifically?

As part of a larger endeavor geared towards designing intelligent educational supports for high-school engineering teachers, we conducted a six-week participatory design (PD) process with two teachers with diverse backgrounds and teaching experiences. For this paper, we focus on two research activities from the PD process focused on student failures, and teachers' prevention and recovery strategies. Our findings suggest that teachers dedicate significant efforts to preventing disruptive failures by constricting design challenges that limit or eliminate the opportunity for students to learn from productive failures, and highlight the need for technological tools for teachers to effectively plan for and prevent disruptive failures while supporting productive ones.

Design challenges and productive failures

Engineering education faces challenges in designing authentic and open-ended design challenges that provide hands-on opportunities for students to apply engineering practices and grapple with real-life situations. Moore et al. (2022) found that, in practice, design challenges are often formulated in ways that restrict the possible solution space, reduce creativity and inventiveness, and undermine students' engineering identity. Promoting ill-structured problem-solving is crucial to prepare students for engineering professions and their challenges (Trueman, 2014). More importantly, Kapur's (2008) productive failure theory contends that problem-solving activities should be designed for students to reach an impasse and generate opportunities for students to explore the affordances and constraints of the problem before consolidating their learning through comparisons and organization of student-generated solutions into canonical solutions (here, analogous to the *evaluation* and *presentation* phases of the EDP). Kapur explains that this structure leads to better performance on both ill- and well-structured problems and increased creativity and transfer of learning. While previous studies focus on implementing productive failure in problem-solving and corroborating its benefits, we use productive failure theory as a pedagogical lens to understand current design challenge formulations focusing on whether those formulations offer opportunities for students to productively fail.

Methods

This study took place in summer 2022 as part of a teacher professional development internship program hosted at a major university in the Southeastern U.S. We selected two teacher interns with different backgrounds and experiences, Macie and Stanley (pseudonyms), to co-design a task model of their students' activities and

challenges to serve as the basis for prototype development of an artificial intelligence-enabled system. Over the six weeks of the program, the teachers participated in eleven participatory design *research blocks*, sessions ranging from two to four consecutive hours dedicated to research activities designed to elicit teachers' tacit knowledge (Moreno et al., 2021) of engineering education and the practical constraints they face. Audio recordings and photos were taken, and all artifacts, including written reflections, curricula designs, presentation slides, flow charts, and task models were collected. For the purposes of this analysis, we focus on two activities, spanning three research blocks: (1) one synchronous research block consisting of a discussion of design challenges, focused on eliciting teachers' practices and priorities when creating and/or choosing design challenges, including the breakdown of the components and properties they consider, and (2) two asynchronous research blocks consisting of a Miro board-based flow chart design activity, asking teachers to document the anticipated obstacles and recovery strategies when students start building the physical prototype – a challenging step according to previous discussions with the teachers. We used Braun and Clarke's (2006) theoretical thematic analysis to qualitatively code the design challenge discussion transcript and the flow charts for mentions of student failures (disruptive or productive) and the strategies teachers use to prevent or repair them.

Findings and discussion

In the design challenge discussion, the total number of failure references is not important since the discussion was free-flowing. However, from the Miro flow chart activity, we extracted a total of 31 digital sticky notes referencing failures. All failures were inductively categorized into three classes: (1) failures related to classroom practices (i.e., students' behavior problems in the classroom such as not following classroom rules or being off-task), (2) failures in engaging with the EDP (i.e., students trying to circumvent completing the steps and/or substeps of the process, such as documentation, reflection, sketching, and planning), and (3) failures tied to design challenges (e.g. failures around the design requirements, materials, tools, and prototype construction such as inadequate materials, improper use of tools, etc.). Within these groupings, failures related to the EDP were documented most frequently (n = 14), with lack of student planning as the most common failure (n = 9).

Across all categories, we found that most failures were disruptive in some way, such as students challenging classroom authority, actively trying to circumvent using the EDP or playing around with materials without learning from the activity. Only three failures were identified by the research team as potential productive failures. Two were categorized as EDP failures: (1) teams not having a plan to handle failed prototypes, and (2) students' building process not going as planned. One was a design challenge failure: student's prototype not working according to the design challenge requirements.

Both teachers described common strategies for mitigating, preventing, or safeguarding against the above failures. We arranged Macie and Stanley's strategies into four categories: (1) adding rules and restrictions to the design challenge (e.g., requiring the use of all EDP steps, limiting materials usage) (2) reflecting and making changes along the process, (3) using extrinsic and intrinsic motivational approaches (e.g., including students' interests in the design brief, giving prizes for documentation), and (4) using outside resources for help (e.g., other teachers' materials posted online, outside curricula such as Project Lead the Way).

Our research surfaced that, in anticipation of failures which are mostly disruptive, teachers constrain the design challenges to become even more prescriptive. These restrictions could preclude productive failures (Kapur, 2008) from happening, which, our research found, are rarely occurring as is. Such a narrow and evident set of solutions could even eliminate the need for and utility of the EDP, ultimately resulting in a lack of understanding of its actual value, and of opportunities for students to apply their inventiveness and cultivate their engineering identities. In their development and implementation of design challenges, teachers need to balance open-endedness, open exploration, and opportunities for productive failures while ensuring that their students achieve the various learning outcomes that will lead to success in the engineering pathway. We need to find ways to support teachers in preventing disruptive failures in order to redirect scaffolding and restrictions towards the appropriate aspects (e.g., supporting students in applying analytical skills and the EDP steps).

References

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