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MIND THE GAP! …between engineers' process safety beliefs and behaviors

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Dr. Cheryl Bodnar is an Associate Professor in the Experiential Engineering Education Department at Rowan University and is currently serving as the Provost's Fellow for Student Success. Recently, the National Science Foundation (NSF) and the Kern Family Foundation have funded her research. Her research interests relate to the incorporation of active learning techniques such as game-based learning in undergraduate classes as well as integration of innovation and entrepreneurship into the engineering curriculum. In particular, she is interested in the impact that these tools can have on student perception of the classroom environment, motivation, and learning outcomes.

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I am an early-career engineering education scholar and educator. I hold a B.S. in Chemical Engineering (with Genetics minor) from Iowa State University, and an M.S. and Ph.D. in Chemical Engineering from The Ohio State University. My early Ph.D. work focused on the development of bacterial biosensors capable of screening pesticides for specifically targeting the malaria vector mosquito, Anopheles gambiae. As a result, my diverse background also includes experience in infectious disease and epidemiology, providing crucial exposure to the broader context of engineering problems and their subsequent solutions. These diverse experiences and a growing passion for improving engineering education prompted me to change career paths and become a scholar of engineering education. As an educator, I am committed to challenging my students to uncover new perspectives and dig deeper into the context of the societal problems engineering is intended to solve. As a scholar, I seek to not only contribute original theoretical research to the field, but work to bridge the theory-to-practice gap in engineering education by serving as an ambassador for empirically driven educational practices.

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Introduction & Background

Engineers make judgements on a daily basis that require them to maintain competing criteria. Yet, within the context of chemical process safety, little is known about how engineers approach making these judgements. Currently, chemical engineering education primarily focuses on hazard identification and layers of protection analysis [1]. As a result, engineers entering the chemical process industry may possess inadequate awareness on how they make process safety judgements that have competing criteria. We see potential evidence of this inadequate awareness through the process safety incidents that have taken place [2] – [5].

Engineers' judgements need to determine priorities among competing criteria. The prioritization they believe they will uphold may differ from the actions they actually take, as actions may be driven by contextual factors. For example, engineering education typically promotes a safety mindset; however, this safety mindset is not always propagated into safety culture [5], [6]. In 2012, engineering management at a Chevron refinery was alerted of a hazardous leak. While the safest response may have been to halt operations, the ultimate judgement from engineering was to maintain operations [3], possibly because they felt the contextual demand for plant productivity. This judgement resulted in a fireball that put workers' lives at risk. Osberg & Shrauger [7] suggest poor judgements caused by inaccurate predictions about oneself can be mitigated by reconciling self-held beliefs with actions actually taken. Therefore, we posit that a pathway to reducing process safety incidents exists through engineers narrowing any gap that may exist between their beliefs about their judgements and their actions as a result of their actual judgements.

Project Objectives

Using simulated contexts with competing process safety criteria, we piloted a study on engineers' believed judgements and their behaviors as a result of their actual judgements. This study is innovative in that it seeks to compare engineers' self-held beliefs about their own approaches to process safety judgements with their (simulated) behaviors in making process safety judgements. We seek to answer the following four research questions: (1) *What do engineers believe about how they make judgements?*; (2) *How do they behave when actually making judgements?*; (3) *What gap, if any, exists between their beliefs and behavior?*; and (4) *How do they reconcile any gap between their beliefs and behavior?*

Conceptual framework

To better understand engineers' beliefs and behaviors when making process safety judgements, we developed a conceptual framework of six criteria that may influence engineering judgement, including: leadership, production, relationships, safety, spending, and time. These criteria were selected for their prevalence in other industries [8] – [11] and from additional incident case studies by the US Chemical Safety Board [2] – [5].

Methods

We conducted a pilot study in the spring 2022 with the goal of testing these methods and affirming viable data could be collected to answer our research questions. We sampled five senior chemical engineering students who were recruited through their enrollment in one of two process safety classes at a Mid-Atlantic university. We conducted the pilot by moving through three study phases (Fig. 1). The first phase focused on obtaining participants' beliefs about their approaches to process safety judgements through interviews, and the second phase obtained participants' actual judgements from their play though of the digital process safety game, Contents Under Pressure (CUP). The third study phase focused on participants' reconciling these differences, when they occur, through a subsequent interview.

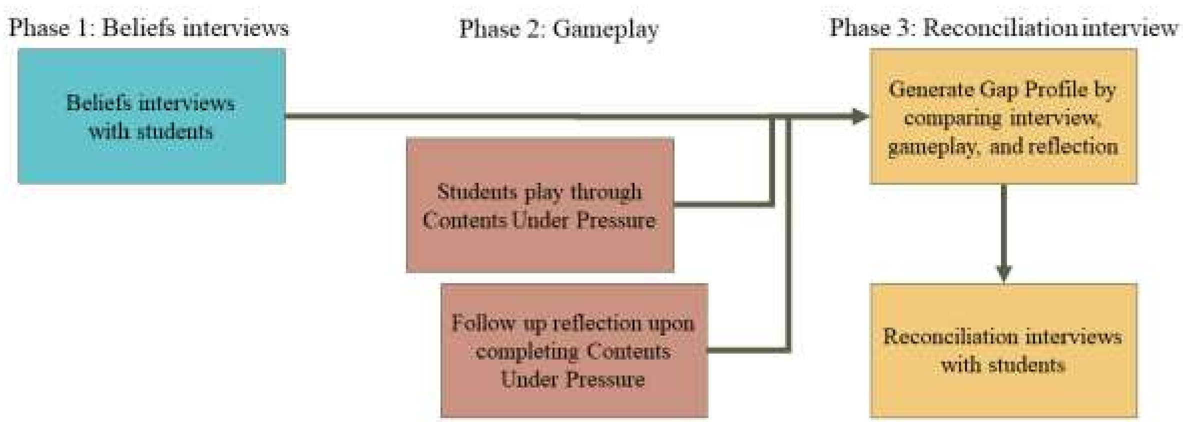

Fig. 1. Phases of analysis to the pilot study.

Details of Gameplay Context: Contents Under Pressure

During the second study phase, participants made process safety judgements within the simulated context of a digital game, Contents Under Pressure (CUP). CUP follows a 15-day narrative where the player assumes the role of a chemical plant manager. Throughout gameplay, the player needs to make a series of judgements on how to manage daily operations, respond to employees, and balance family matters. The game provides players with two pre-constructed responses to every posed scenario; these responses implicitly require the player to trade off criteria relevant to the scenario. Responses are immediately reflected in the in-game metrics (time, safety, reputation, and productivity) shown with icons on the top of the screen (Fig. 2). CUP is appropriate as an educational game because it is safe from real-world repercussions but still allows for measuring authentic judgements due to the immersion in the contextual scenarios. Further details about the game can be found in other publications [12], [13].

Fig. 2. Screenshot of Contents Under Pressure Gameplay.

Phase 1: Beliefs Interviews

The first phase of this work involved interviewing students on their beliefs about how they make process safety judgements. During the interview, participants ranked the set of six competing criteria from the conceptual framework and described the reasoning behind their ranked priorities. We also presented five scenarios that juxtaposed two criteria and that are decontextualized versions of a scenario they would face during gameplay in Phase 2. Participants indicated how they believed they would make the judgement, their reasoning, and any considerations they believe could have influenced their judgement. We analyzed the transcribed belief interviews through holistic coding to characterize how participants believe they approach making judgements. Moving beyond the pilot study of this project, characterizing students' approaches to judgements from the beliefs interviews will allow us to answer the first research question regarding participants' beliefs about their own process safety judgements.

Phase 2: Gameplay

After completing the beliefs interviews, participants played through CUP. Over the course of the game, participants make almost 300 judgements, including how to respond to the same five scenarios that we posed to them during the initial beliefs interviews. Using judgements across the game narrative, we generated a standardized percentage of the rate that each criterion was prioritized or disregarded to represent criteria rankings based on behavior. Immediately after completing the game, participants completed a post-game reflection where they re-ranked the six process safety criteria and provided justification for their judgements within CUP, allowing them the opportunity to offer any contextual justifications for their behavior. After the pilot study, the gameplay and reflection data will contribute to answering the second research question regarding how engineers actually behave while making process safety judgements.

Phase 3: Reconciliation Interviews

During the third phase of this work, we used convergent analysis to compare participants' beliefs from their interviews to their actions that were made during CUP gameplay. In doing so, we developed a Gap Profile (Fig. 3) that visualizes any gaps between participants' beliefs about how they would prioritize criteria (phase 1) and their actual prioritization and reflection of criteria during gameplay (phase 2). Developing these Gap Profiles contributes to answering the third research question regarding differences between beliefs and behaviors, beyond this pilot study. Finally, we presented participants with their Gap Profile in a subsequent reconciliation interview, where we collected data to enable us to characterize their reactions and justifications to any gaps between their beliefs and behavior. The Gap Profile tabulates criteria rankings to be compared across the beliefs interview, gameplay, and reflection. Next, horizontal stacked bar charts compare the five scenarios with juxtaposing criteria. The bar shading shows what percentage of times each criteria was prioritized within gameplay, and the circling shows the exact judgements within each context (beliefs interview shown with dashed oval and gameplay shown with solid oval). Analyzing the data collected from reconciliation interviews from a broader version of this study will allow us to answer the fourth research question regarding how engineers process their potential gaps in judgement.

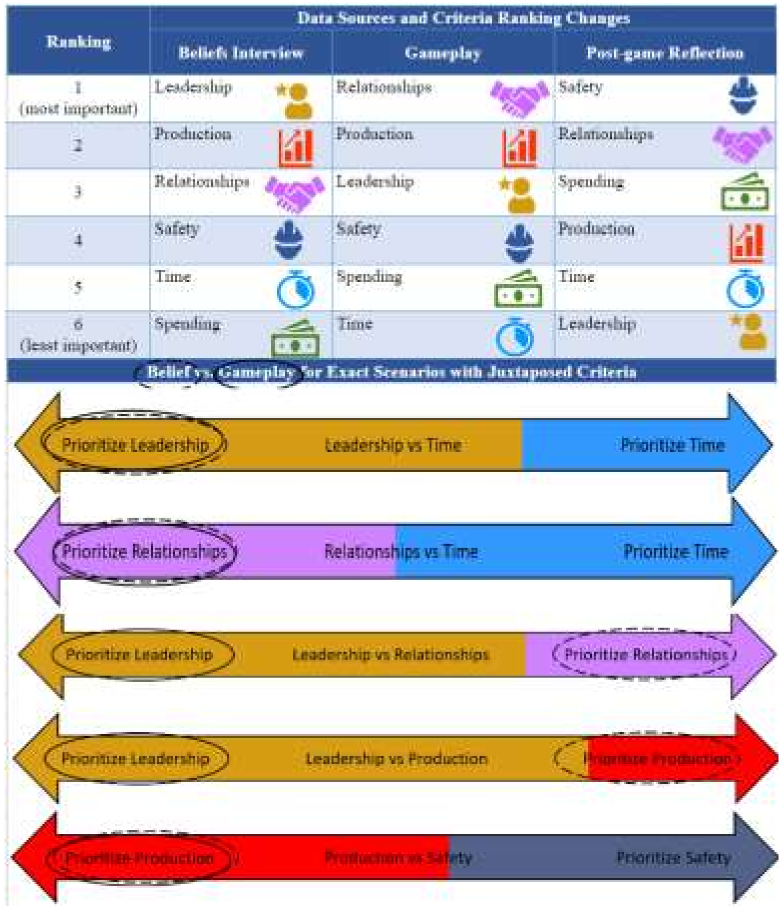

Fig 3. Sample Gap Profile that was used with pilot students in Spring 2022.

Pilot Study Takeaways

The purpose of this work was to pilot this study's methods and affirm collected data could be used to answer our research questions. Throughout the data collection period of this pilot study, we identified a few deficiencies in the protocol. After interviewing the senior chemical engineering students on their beliefs, it became apparent that they may lack practical knowledge and experience with the impacts of company spending or production, making it difficult for students to formulate any concrete beliefs about these criteria. Moreover, the game provides feedback to students through in-game metrics (time, safety, reputation, and productivity), which may have influenced students' beliefs regarding the six process criteria during the post-game reflection. Moving forward, we may need to more clearly differentiate the metrics in the game from process criteria to provide better clarity with the judgements they are making. During the reconciliation interviews, students often reflected on their in-game judgements by acknowledging nuances of the scenario presented in the context of the game. To ensure students are able to adequately reconcile this, it may be helpful for students to visually see their game data (metric scores) across their gameplay. These takeaways will guide our approach to future replications of this work. We believe that the data we collected as a result of this pilot can adequately answer our four research questions with access to a larger sample size.

Future Work

Upon amending the study based on community feedback obtained during the ASEE NSF poster session, we will expand this study during the fall 2022 semester to include fifteen engineering students, tripling the sample size of this pilot. We also plan to run this same study with practitioners (after performing a pilot) to investigate if any differences exist between these two populations.

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