International Journal of Engineering Education Vol. 42, No. 2, pp. 483–495, 2026
Printed in Great Britain

0949-149X/91 $3.00+0.00

How Engineering Practitioners and Students react to Gaps between their Beliefs and Behaviors*

SHERRI YOUSSEF
The Ohio State University, 174 W.18th Avenue, Columbus, Ohio, 43210, USA. E-mail: youssef.28@osu.edu

AMANDA SINGER NAULT
The Ohio State University, 174 W.18th Avenue, Columbus, Ohio, 43210, USA. E-mail: singer.334@osu.edu

CAYLA RITZ
Rowan University, 401 North Campus Drive, Glassboro, NJ 08028, USA. E-mail: caylaritz@gmail.com

BRITTANY BUTLER-MORTON
Rowan University, 401 North Campus Drive, Glassboro, NJ 08028, USA. E-mail: butlerb0@rowan.edu

EMILY DRINGENBERG
The Ohio State University, 174 W.18th Avenue, Columbus, Ohio, 43210, USA. E-mail: dringenberg.1@osu.edu

CHERYL A. BODNAR
The Ohio State University, 174 W.18th Avenue, Columbus, Ohio, 43210, USA. E-mail: bodnar.90@osu.edu

ELIF EDA MISKIOĞLU
Bucknell University, 1 Dent Drive, Lewisburg, PA 17837, USA. E-mail: elif.miskioglu@bucknell.edu

Engineers are socialized to believe they make rational judgments by objectively using logic. This belief is at odds with engineering practice, where judgments are typically complex and difficult to quantify. Researchers have established that what individuals believe they will do and how they actually behave is often not the same. This gap can be particularly problematic for engineers where the judgments they make have significant implications not only for their organizations but the broader community and environment. Increasing engineers' awareness of gaps between their beliefs and behavior is important to help generate awareness of any discrepancies that may need to be mitigated in future judgments. We explored how engineering practitioners and students reacted when made aware of gaps between how they thought they would behave (espoused beliefs) and how they behaved when making judgments in the context of a process safety game (simulated gameplay behavior). Specifically, we answer the following research question: How do engineering practitioners and students react when presented with gaps between their espoused beliefs and simulated gameplay behavior? We conducted and analyzed qualitative, semi-structured interviews during which participants (13 industry practitioners and 12 engineering students) were asked to respond to the gaps that previous analysis had identified between their espoused beliefs and simulated gameplay behaviors. We used inductive coding strategies to develop themes characterizing their ways of reacting and then used pairwise comparisons to compare the reactions of practitioners and students. When presented with a gap in their espoused beliefs and simulated gameplay behaviors, engineering practitioners and students reacted in both similar and different ways – they equally blamed elements of the game for causing these gaps, citing boundaries posed by the game as limiting their desired behavior. In addition, practitioners tended to invoke their prior experiences and describe the parallels between the game and reality, but were less likely to engage in reflection when presented gaps. Meanwhile, students tended to engage in reflection, discussing changes to their future behaviors and beliefs. Students' justification of their gaps also referenced a desire to "win" the game which showcased the influence of game-based elements, such as scoring metrics, had on their behavior. These findings suggest that students are more likely to engage in reflective thinking, highlighting tailored interventions that raise awareness of belief-behavior gaps for students transitioning into professional roles.

Keywords: engineering profession; process safety; qualitative; senior; reactions

1. Introduction

In today's world, engineering students need more than just the technical skills associated with being engineers – they must possess strong communication [1], teamwork [2], and problem-solving skills [3], as well as cultural competency [4] to operate in our global economy. Equally important to the contemporary engineer's skillset is the ability to make decisive and sound judgments. The judgments engineers must make are complex and situationally dependent [5, 6], the same as any other real-world judgments [7]. Because of the complex nature of these judgments, engineering students must practice thinking through them while still in school so they may confidently navigate such judgments in

* Accepted 3 November 2025.

industry. One way to do so in a safe and scalable way is through the use of games, which simulate real world judgments and allow students to practice making them in a context with competing factors. However, providing students with practice to make these judgments is only a piece of the puzzle – students must also be aware of how their judgments, behaviors, and beliefs align (or not), because without this awareness, students may unknowingly contribute to process safety accidents when in industry.

2. Background

Engineering practitioners regularly face complex judgments in their line of work, even though they are socialized to believe they make objective judgments. This can cause gaps between their beliefs and the behavior they exhibit. Such gaps have been found in non-engineering contexts, and the reactions of individuals when presented them warrant an investigation into how engineering practitioners react when gaps arise in their work.

2.1 Engineers are Socialized to Believe that they Can and Should Approach their Professional Judgments Objectively and Rationally

Assumptions of rationality are embedded into engineering culture [8]. Picon [9] identified rational reasoning as the single theme that cuts across all disciplines of engineering. Engineers understand their field to be centered on rationality [8, 10, 11] and the public image of engineering is such that non-engineers often subscribe to a "rational fallacy" that engineering judgments are the result of strictly logical and rational processes [12]. Engineering students and faculty alike recognize the powerful social norm for engineers to portray their work as strictly rational [13]. An overemphasis on objectivity in engineering is perpetuated through the structure of undergraduate engineering education, where engineering students engage with primarily well-structured problems [14–17] and instructors emphasize the use of rational approaches, even to the open-ended and ill-structured practice of engineering design [18]. An emphasis on solving problems mathematically and a denial of the sociocultural or political complexity in which engineering judgments are embedded is central to engineers' education [19, 20]. It is not surprising, then, that senior engineering students express the belief that the keystone of engineering practice (i.e., design), is a "trivial extension of mathematical problem solving" [21, p. 168]. Further, research findings suggest that engineering students' beliefs about how engineering design judgments are made remain stable through their senior year [22].

2.2 In Reality, Engineers' Workplace Behavior includes making Judgments in the face of Uncertainty and Complexity, Overriding the Objectivity they are Socialized to Apply

Engineers contribute to challenges that are inextricable from their complex social, cultural, and political contexts. Scholars have strongly argued that the division of the social and technical aspects of engineering work is false and problematic [10]. Regardless, engineers continue to be socialized in ways that reinforce the idea that their role can and should be purely technical in nature [23]. Even engineering faculty remain largely resistant to the recognition of the socially embedded nature of engineering work [24] and default to focusing on the quantifiable parts of engineering design – not because it is realistic, but because it is easier to do [13]. Engineers cannot and do not rely on rational processes alone to make professional judgments. Human cognition fundamentally leverages both slow, potentially rational processes along with more automatic or intuitive processes [25–28]. There is little doubt amongst researchers that people consistently fail to use strictly rational approaches [7]. Further, scholars have shown that in the engineering workplace, problems are complex and without a "correct" answer because they possess conflicting goals, multiple solution methods, non-engineering success standards and constraints [5]. As judgment makers, engineers are functioning within a team and workplace environment, where they are influenced by relationships, social norms, policies, culture, and innumerable other factors [29]. In fact, scholars have shown that solving real-world problems requires engineers to use different skill sets and expertise throughout the process, beyond just rationalistic approaches [29, 30].

2.3 It is Important to be Aware of any Gaps that Exist between how Engineers believe they will Behave and how they actually Behave

Gaps between engineers' beliefs and behavior regarding workplace judgments are particularly critical in high-risk engineering environments, such as chemical process safety, where engineering judgments directly impact public safety, sustainability, and economic prosperity [31]. If engineers believe they will always prioritize safety and remain immune to contextual influences, they may lack the self-awareness necessary to recognize and address discrepancies between their intentions and actions. Understanding these gaps is essential for developing effective strategies to mitigate risks associated with engineering judgments. While engineers in industry have years of experience navigating real-world complexities, competing factors, and workplace pressures, engineering students have primarily been exposed to structured academic problems with clear solutions [14–17]. Moreover, unlike practitioners who have developed intuitive judgment-making skills through lived experience [32], students are still learning how to approach engineering judgments in multifaceted environments. This distinction highlights the importance of studying engineering students' beliefs and behaviors before they enter industry. Identifying potential misalignments in engineering students' judgment-making during their education helps prepare them for the realities of professional engineering practice. Well-documented case studies on process safety incidents frequently cite breakdowns in engineering judgment due to competing factors as key contributors to disasters [33]. Additionally, SPHERA's annual safety report found that 66% of surveyed professionals attributed safety inadequacies to tensions with competing factors, such as production expectations or staffing limitations [34]. Although glaring misalignments between beliefs and behaviors – such as prioritizing plant production over addressing safety concerns despite workers' unified agreement to stop [35] – can be observed in extreme cases, subtle gaps are often difficult to recognize.

One reason for this challenge of observing subtle gaps is that beliefs exist at multiple levels: explicit beliefs that individuals can articulate (espoused) and subconscious beliefs that influence their judgments without conscious reflection (implicit) [36]. Implicit beliefs may shape how engineers approach judgment-making, yet individuals often lack awareness of how these beliefs were formed [37].
Additionally, beliefs are frequently grounded in personal experiences [38]. If an individual has limited exposure to a particular context requiring judgment, they may feel less confident in their resulting behavior. This issue is particularly relevant for engineering students, who lack the breadth of professional experiences available to practitioners. Addressing these gaps during their academic training ensures they enter industry with a more nuanced understanding of judgment complexities, better preparing them to navigate competing factors and external influences in real-world settings. To systematically identify gaps between engineers' beliefs and behaviors, we developed a methodology that examines how individuals react to process safety judgments in a digital game environment with multiple competing factors [39]. While documenting these gaps is a crucial step, our broader goal is to empower engineers to engage in reflexive practices that enhance their judgment-making.

2.4 It is Important to Understand how People React when made Aware of any Gaps between their Beliefs and Behavior in an Engineering Context

It is important to understand how engineers and engineering students react to their own beliefs-behavior gaps given the reactions found in other contexts. For example, scholars have investigated reactions to the Implicit Associations Test (IAT), which is a quantitative instrument designed to reveal implicit biases based on participant reaction times. Through passive qualitative analysis [40], Schlachter and Rolf [41] found individuals with a reported gap between their espoused beliefs and test results had reactions that ranged from trying to make sense of (sensemaking) the potential origins of the gap to questioning the power and reliability of the test. Others expressed anger and frustration at the IAT, blaming it for the results they received and staunchly believing their espoused beliefs to be true. Similar to these findings, Howell et al. [42, 43] reported that participants enacted a defense mechanism to IAT results that were indicative of espoused-implicit belief misalignment. Gaps exhibited in the IAT context tended to yield negative responses as many perceived their results to threaten their identity [41, 44]. This literature sheds light on the existing challenge of not only identifying gaps, but actually getting individuals to process gaps between their beliefs and behavior. If denial or dismissal is the primary reaction, reflection and changed behavior is unlikely.

With such reactions to gaps present in other contexts, the question remains as to how such gaps are perceived in engineering, where judgments made can profoundly impact the safety of others at a large scale. Are gaps perceived in similar ways to the IAT, do gaps prompt reflection and change among individuals, or does the response vary from engineering practitioners to students? In this contribution, we explore how participants react when we reveal to them any gaps between their beliefs and behavior.

3. Research Question

We seek to address the following research question:

How do engineering practitioners and students react when presented with gaps between their espoused beliefs and simulated gameplay behavior?

4. Methods

We conducted this study in three phases and with two types of participants (engineering practitioners and engineering students; known as practitioners and students respectively hereon) to answer our research question.

4.1 Participants

Participants in this study included 13 industry practitioners with an engineering degree who had prior experience with process safety and 12 upper-level engineering students enrolled in a chemical engineering process safety course at a Southern Atlantic university. We invited engineering students to participate in the study through an announcement from their course instructor. Interested students were able to sign up for the study by completing a Google form which asked for students' name and e-mail address, along with an indication of whether they consent to participate in the study. We obtained 18 consenting student submissions, and randomly selected 15 to participate in the study of whom 12 ultimately completed the study. Student data was collected during the Fall 2022 and Spring 2023 semester. We obtained IRB approval and participant consent prior to data collection, and students were compensated with a $50 electronic gift card upon completion of the study.

We recruited industry practitioners through internal connections from the research team, announcements posted to LinkedIn, and from contacts made through presentations at a national chemical engineering conference. Practitioners were required to be working or have worked in an engineering role and have prior experience with process safety judgments. Interested applicants completed a brief interest survey that replicated the one used for the student study described earlier. We obtained responses from 21 practitioners, and randomly selected 15 to participate in the study of whom 13 ultimately completed the study. We collected practitioner data during the Spring 2024 semester. We obtained IRB approval and participant consent prior to data collection, and practitioners were compensated with a $50 electronic gift card upon completion of the study.

4.2 Data Collection

Both practitioners and students participated in the same three-phase study to collect data on their approach to process safety judgments: (1) Initial Beliefs Interview, (2) Process Safety Digital Game Play, and (3) Reconciliation Interviews. The Reconciliation Interview transcripts were the data set of the larger project used for the analysis and findings reported here. Fig. 1 provides a visual representation for this study design.

The first phase, the Beliefs Interview, was a semi-structured interview that consisted of two sections. In the first section of the interview, participants were asked to rank six factors in order from most to least important when making process safety judgments and provide rationale for their rankings. These six factors were determined from a previous review of literature as competing when making process safety judgments, and include safety, production, spending, relationships, leadership, and time [45, 46]. In the second section of the interview, participants responded to five hypothetical scenarios, pulled from the Process Safety Digital Game Play, by selecting one of two responses that were presented to them and providing rationale for their judgments. Unknowing to the participants, these scenarios juxtaposed two of the previously stated six competing factors. One of the hypothetical scenarios and its corresponding response options is given below:

You had to stop production in the plant due to a nasty hurricane. Due to previous incidents, two of your engineers are on injury leave. Your supervisor, Wanda, approaches you and demands, "Alright, what is happening down there? Every day the unit

Fig. 1. Overall Study Design.

isn't running is affecting profit." Your options are to respond with:

[A] "I'm trying my best, but two operators are injured. We're pushing through the night.

or

[B] "My top priority is getting my two injured employees medical attention. Profit can wait."

Which would you choose and why?

Upon completion of the Beliefs Interview, participants were sent a link and instructions to complete a process safety digital game called *Contents Under Pressure (CUP)* [47]. In the game, participants took on the role of a chemical plant manager overseeing a chemical plant over 15 in-game days. Participants responded to 12–15 prompts per in-game day which impacted four game metrics: time, safety, reputation, and productivity. These four game metrics corresponded to the previously mentioned six factors with "reputation" combining relationship and leadership and "productivity" combining production and spending. Game data was collected from the participants to determine how they were ranking the six competing factors within the game, and how they responded to the five scenarios which were presented in the beliefs interview. Upon completion of the game, participants were asked to complete a follow-up survey where they ranked the six competing factors based on how they believed they prioritized them within the game.

In the final phase of the study, participants partook in the Reconciliation Interview, which was a semi-structured interview where they reconciled any differences between the judgments they made in the Beliefs Interview, and their behaviors within *CUP* (i.e., gaps between their espoused beliefs and simulated gameplay behavior). In the first half of the interview, participants were provided with the results of our analysis: a comparison of their initial ranking of the six competing factors, and how they prioritized the factors within the game. They were then presented with a comparison of the prioritization of factors within the game and the ranking they provided in the follow-up survey (Fig. 2). Participants were invited to make sense of any differences in the rankings.

In the second half of the interview, participants revisited the five hypothetical scenarios and were provided their responses from the Beliefs Interview, and the judgments they made within the game (Fig. 3). Participants were asked to make sense of any differences or similarities. Additionally, the juxtaposition of the two possible response options was revealed to the participants, and a stacked bar chart that showed how often participants prioritized one factor over the other within the game was also presented to them for their personal reflection. Participants were asked if this stacked bar chart (Fig. 3) reflected how they made judgments in their current role, and to support their responses.

4.3 Data Analysis

Transcripts of participant Reconciliation Interviews generated by Zoom were first checked for accuracy by a member of the research team and de-identified for analysis and publication purposes. After cleaning the transcripts, an initial, deductive

Data Sources and Criteria Ranking Changes

Ranking	**Beliefs Interview**	**Gameplay**	**Post-Game Reflection**
1 (most important)	Safety	Relationships	Safety
2	**Spending**	**Leadership**	**Relationships**
3	Relationships	Spending	Spending
4	**Leadership**	**Safety**	**Leadership**
5	Productivity	Productivity	Time
6 (least important)	**Time**	**Time**	**Productivity**

Fig. 2. Example Reconciliation Interview Composite: Comparison of Criteria Rankings across Study Phases.

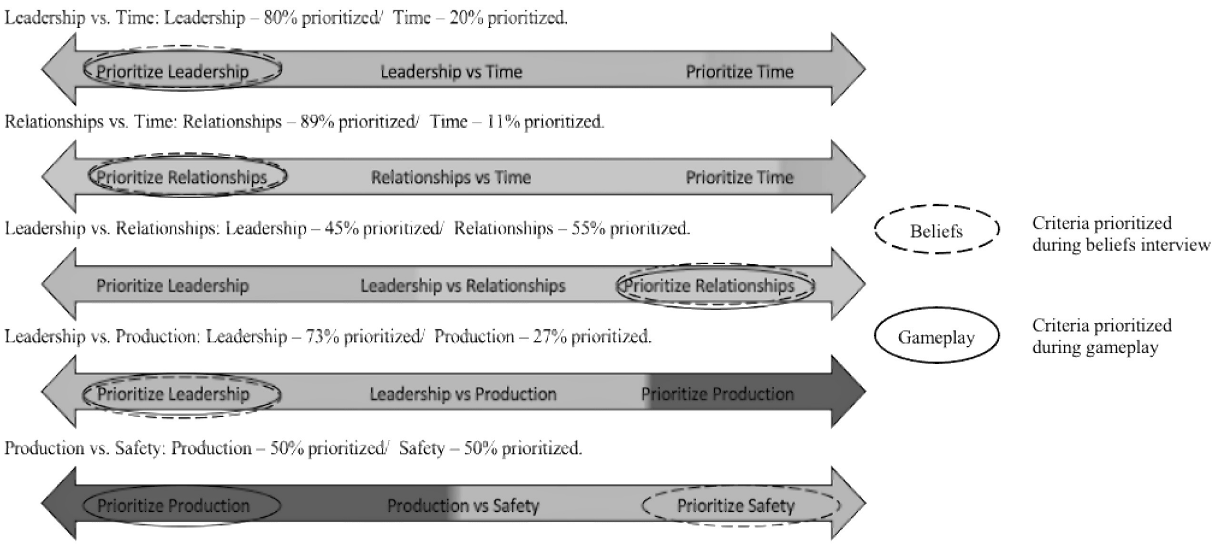

Fig. 3. Example Reconciliation Interview Composite: Comparison of Responses between Beliefs Interview and Gameplay.

round of coding [48] was conducted by the team to identify instances where practitioners and students articulated thoughts about a gap in their espoused beliefs and simulated gameplay behavior. This deductive coding process allowed the team to pinpoint moments where participants were reacting to inconsistencies between their espoused beliefs and simulated gameplay behavior within the gameplay context, allowing us to focus on the data directly related to our research question. Following this deductive coding cycle, we employed inductive coding techniques to explore how participants reacted to being made aware of gaps between their espoused beliefs and simulated gameplay behavior. Inductive analysis, recognized for its robustness in qualitative research, involves a systematic process of reading through data to identify emergent codes, categories, patterns, and themes [49, 50]. Unlike deductive approaches, where codes are predefined, inductive coding allows codes and categories to evolve naturally from the data itself. We began with open coding, where essential concepts and patterns in participants' responses were identified and named [51]. This initial coding [52] served as the foundation for subsequent analyses and was appropriate given the exploratory nature of our research question. Using the constant comparative method, Authors Youssef and Singer Nault continuously compared data points and codes within and across participants to refine the team's understanding and to develop categories and themes. This iterative process of coding data, comparing findings, and condensing them into meaningful themes revealed how participants reacted to the gaps between their espoused beliefs and their simulated gameplay behavior.

To address our research question regarding the comparison of reactions between practitioners and students, we used descriptive statistics to analyze how many participants from each group referenced specific themes. Upon finalizing the coding of the qualitative data from both groups, we determined the proportion of practitioners and students whose transcripts contained each theme. These proportions were then converted into percentages to provide a clearer comparison of the prevalence of these themes within each group. This method allowed us to identify notable similarities and differences in the reaction to gaps between process-safety beliefs and behaviors between practitioners and students, offering a structured basis for our comparative analysis.

4.4 Research Quality

To ensure qualitative validity when collecting and analyzing the data in this study, we use the Qualifying Qualitative Research Quality (Q^3) framework to ensure appropriate measures were taken in making and handling the data [53, 54]. With regards to procedural validation, multiple researchers were included in the data analysis process to maintain levels of reliability. To ensure process reliability, researchers recorded interviews through Zoom to obtain transcripts, maintained an audit trail for the study detailing data collection and analysis processes for repeatability, and verified all collected transcripts through a standard operating procedure (SOP).

4.5 Research Positionalities

As authors, we acknowledge that our positionalities have shaped the research process, from the initial project conceptualization to the recommendations presented in this paper. Except for author Butler-

Morton, who has prior experience in process safety roles, our collective expertise in process safety judgment is primarily within academic settings, with authors Bodnar and Miskioğlu teaching chemical engineering courses. Although each member of our team holds an engineering degree, our approach to this research is fundamentally academic and theoretical, reflecting our limited practical experience as process safety engineers in industry. Therefore, our interpretation of the results and conclusions that we draw from them, along with the recommendations that we make, is influenced by our positioning as "outsiders" and our lack of contextual knowledge about process safety judgments.

5. Results

One similarity and several differences exist in the ways practitioners and students reacted to gaps between their espoused beliefs and simulated gameplay behavior. Both reacted by identifying elements of the game as unrealistic, but differed in their overall approach to and reflections on the game. Specifically, students described how the game-based nature of the intervention motivated them to approach gameplay by making judgments that helped them "win" the game rather than how they would make process-safety judgments in real life [45]. In terms of their reflections on the game, practitioners described how the game paralleled their real-life experiences, while students were more likely to reflect and express an increasing awareness of the complexities associated with process-safety judgment, including the tensions that arise when balancing factors.

5.1 Practitioners and Students Describe how the Game poses Boundaries on their Approaches to Judgments, which caused their Belief-behavior Gaps

Both practitioners and students claimed that the game's structure unrealistically inhibited their full judgment-making ability – roughly 75% of all practitioners and 75% of all students interviewed indicated at least one such occurrence. Participants had noted as well that this caused some of their belief-behavior gaps. In one such scenario, production at the simulated plant is halted due to two injured employees and a hurricane passing through. The plant manager demands an answer for the halted production, and the participant can respond by prioritizing production and operating through the night or prioritizing safety and keeping production at a standstill. Practitioner Ibex describes their reaction to this scenario and how it caused their belief-behavior gap:

> "The whole thing [operating during a hurricane] is outside of the universe of what I would have wanted to happen for the whole thing in the first place. I would have been in a shutdown procedure, and I wouldn't have been thinking of my injured employees. It probably wouldn't have occurred because if it's a nasty hurricane, I would have already shut down the plant."

In another recurring scenario, participants had a choice between having lunch with an employee or continuing to work through lunch. Student Delta discusses how they agreed to have lunch with an employee at the beginning of the game to resolve the arguments occurring between that employee and another. However, they chose to decline all remaining lunch invitations in the game since this one did not resolve any of the issues between their employees, creating a belief-behavior gap:

> "I think in real life if I was going to have lunch, I would just eat with people cause it's easy to do both. In the game, I felt like I had to choose between doing more work versus having lunch, and the one lunch I did go to I thought it was useless, so I just didn't go again."

Delta perceived the binary nature of game responses as a limiting factor that prevented them from doing both even though they would in reality and viewing all remaining lunch invitations as a "waste." They expressed a belief in prioritizing relationships, leadership and spending highly and, because the first lunch invitation did not resolve employee issues, they then prioritized relationships the least in their simulated gameplay behavior, creating a belief-behavior gap.

5.2 Practitioners Cited their Lived Experiences, and Noted that some of the Complexity Represented in the Game Aligned with these Experiences

When reacting to belief-behavior gaps present, practitioners typically cited prior experiences gathered from their careers. Practitioner Kingfisher presented an example of this, where their espoused beliefs prioritized spending over time even though their simulated gameplay behavior yielded a greater prioritization of time over spending. They responded to this gap with the following excerpt:

> "So I have a son, but time or two I've [stayed late at work and missed time with family] where I said 'Hey, well, Dad can't come home right now. He's got things to do with the plant.' And so we worked through it. So I think I was a little more sensitive than some other people I've run across in a plant environment at the time toward that. But all in all, it was you know, when you have an incident like that's kind of a no-win situation to try to try to get through it."

Practitioners also tended to cite the influence of various co-workers in the game when justifying belief-behavior gaps. Specifically, they would respond to the engineering manager in ways that they believed would best cater to their manager's desires while their response to employees depended on the employee posing the question. Practitioner Elephant provided an excerpt that aligns with this latter point. Elephant is posed with a scenario before and during the game where an employee asks for an extension on a report that is due at the end of the day. Two possible responses to this question are provided: (1) to give the employee an extension and prioritize leadership, or (2) to hold the original due date and prioritize production.

> "I think it definitely did [influence the response] like if it was the more experienced employee who had been at the company longer, and kind of knew what was going on. I would have been a lot more willing to say 'get it done tomorrow' at the end of the day. But with Victor, yeah I would have gone with the strict deadline'.

Elephant expressed a belief in prioritizing leadership over production for this scenario (Option 1) while their gameplay behavior prioritized production (Option 2). Throughout the game, one of the employees, Victor, is seen as an unreliable employee who is difficult to work with, and Elephant describes how these qualities of Victor are primarily why they chose not to grant them an extension. This result indicates how various qualities and circumstances that may not be readily apparent within a hypothetical scenario can inform one's behavior in ways that generate belief-behavior misalignment.

While most practitioners found the bounds posed by the game on their judgments unrealistic, they also identified elements of the game that paralleled reality more than students did – two times the number of practitioners noted the realism of the game or realistic elements of it than students did. Elements of the game that practitioners described as realistic typically related to the experiences they had in their career. Practitioner Lynx described the parallels between the hurricane situations in the game and what they encountered in industry:

> "The hurricane situation is a good example. I mean, our organization has an extremely detailed plan and levels of activity or an action that will occur based on the proximity of the hurricane, even have it zoned, you know, like 'Hey, we're in level one of hurricane prep'. That's like when the season comes upon us. You know, there's certain things that we have to go through to make sure readiness is there, and then the level of readiness increases the closer it gets, and it's all defined you know, in a very extensive document as to what you're gonna do. For instance, like they order on site generation abilities and hook them up when the hurricane season begins just as a you know, we don't have any idea there's no hurricanes actually, you know, in existence. But that's the first thing you do. You get all that stuff on site. You do certain other things. You select the known manning teams and all that kind of stuff just so that they're available, and know that they've volunteered for that work in advance and a whole host of other things because of that, so. And the game, of course those were dropped on you which is fine, I think that makes sense in terms of a measurement of what you're after. But I was also approaching some of those answers in that reflection of 'Well, I would have already had that done. So, you know that kind of thing. So I found that [the hurricane scenarios] fascinating".

Practitioner Antelope provided similar sentiments of the game's realism at a higher level:

> "I think the game does a pretty good job overall. Some of the choices are, it's tough to juxtapose things where maybe in certain situations you would just do both of those things instead. But you know if it has to force a choice A or choice B, I think it does a pretty good job of it. It's relatively realistic, for the most part".

5.3 Students also attributed Belief-behavior Gaps to their Approach to "Win" the Game

Students also reacted to gaps by explaining how they were driven to "win" the game. Specifically, 83% of student participants described how their desire to "win" the game influenced their simulated gameplay behavior at least once and gave rise to the gap. This is an interesting finding that illustrates how students' can be extrinsically driven by achievement and point systems. Discussions that revolved around these responses typically attributed the game to "forcing" their behavior, behaving based on gameplay metrics at the top of the participant's screen, or a desire to "win" the game. Student Aaron explicitly described the game-based nature of the activity as an informant of their behavior as opposed to their beliefs:

> "I feel like part of it was I wanted to win. So I was willing to sacrifice a little bit of stuff that I might not be willing to in the real world [. . .] as soon as I was actively trying to win the game. My time was too thin, spread too thin."

Gamifying their experience and all aspects of the game yielded behavior that did not align with their beliefs. It also led to adverse effects in other elements of their gameplay, namely, the de-prioritization of time which they previously indicated as their top priority. Aaron understood their desire to "win" the game changed their behavior in the previous excerpt and elaborated on why they would behave differently in reality:

> ". . . but I feel like in the real world. I might not like make such a cut and dry decision, and if there was an issue that like where to sacrifice production over safety. Then I feel like I might not make that decision so like so readily. I might talk to people first about it. I feel like it wouldn't have to be such a like a big trade off between the two."

These excerpts from Aaron depict an understanding that they knowingly and willingly exhibited a change in goal-directed behavior when that goal was to "win" the game. It demonstrates the power of competition as an extrinsic motivator and a performance goal orientation on one's behaviors over their beliefs.

5.4 When Students were unable to Explain a Belief-behavior gap, they Engaged in Reflection and Recognized the Complexity of Balancing Factors when Making Process Safety Judgments

Students engaged in personal reflection when unable to explain a belief-behavior gap more than practitioners. In total, only six out of thirteen practitioners incorporated reflections into their reconciliation discussions while eleven of the twelve students did. Specifically, students were more inclined to reflect on realizations about themselves and what they prioritize when making process safety judgments, with seven out of twelve students expressing newfound insights, compared to only two practitioners. Interestingly, of the students who provided such reflections during their interview, four of the seven discussed a newfound value in leadership in process safety environments. Student Aaron discusses how the *CUP* experience made them realize the importance of leadership. They state:

> "The game kind of helped me realize that [leadership] is probably much more important than I had originally thought . . . I feel like in the real world having a really strong leader who knows what they need and is organized would allow for the other categories [factors] to, like, be met more easily. I think good leadership would probably correspond to higher safety and higher production."

When shown the comparison of their beliefs and simulated gameplay behavior, Student Echo also verbalizes their realization of the importance they were placing on leadership during the game.

> "I feel like they're [beliefs interview and gameplay factor rankings] pretty much same except for the leadership one. So I guess I didn't realize how much I like put importance on that."

Similar realizations regarding their prioritization of the process safety priorities not only prompted discussions about their future behaviors but also potential changes in their beliefs about their approach to process safety judgments. Student Kangaroo reflects on the impact the game had on their future actions if faced with a situation where safety and spending are in competition with one another.

> "It [Content Under Pressure] definitely makes me reflect like when I'm actually working which one will I prioritize. I know, working at any company, they're going to have a big push for spending and cutting costs. So, I guess, making sure that I prioritize safety over things would definitely be something I want to focus on because, I mean there won't be [a] bar that shows how much I'm spending, but I'm sure there'll be like some type of external pressure. I mean at the end of the day I think safety should be more important."

Kangaroo's reflection highlights how, in the future, they hope to champion safety in their judgments. This reflection emerged from the presentation of their simulated gameplay behavior relative to their beliefs, where safety was ranked third overall in factor prioritization, with spending and relationships being ranked first and second respectively. This gameplay outcome contradicts Kangaroo's stated belief that safety should always come first. Therefore, the quoted reflection underscores their commitment to modifying their behavior to align with their previously stated beliefs and aligning future actions accordingly with real-world practice.

6. Discussion

In this work, both engineering practitioners and students engaged in interviews about their *CUP* simulated gameplay behavior and espoused beliefs related to several process safety factors. Through these interviews, we explored participants' reactions when presented with belief-behavior gaps, allowing us to distinguish similarities and differences in their reactions and infer why they do this.

Practitioners' reactions of invoking their prior experiences align with findings from Jonassen et al. [5]. Jonassen et al. [5] found practicing engineers to rely extensively on their prior experiences when encountering and solving new problems by applying case-based reasoning (CBR). With CBR, both information about the prior experience and lessons learned from it are recalled and used in new situations [55]. Practitioners in our sample appeared to have actively engaged in CBR during the reconciliation interviews and elaborated on the prior experience they would recall when encountering the various game scenarios. However, their use of prior experiences to justify their simulated gameplay behavior suggests practitioners were less likely to use the game as a learning experience and evaluated the judgments made in the game against their prior experiences instead. This response to the game aligns well with the experts' susceptibility to cognitive entrenchment [56]. With cognitive entrenchment, experts are more likely to lean on their prior experiences and expertise when in new scenarios rather than use it as a learning experience. Similarly, Stone and Heen [57] provide an explanation of how one may choose not to use a learning experience in a constructive manner based on their own impressions of themselves and their work. In the context of this work, we suspect practitioners recognized that the complexities of the game paralleled the complexities of what they may experience as a chemical engineer in industry, and subsequently chose to evaluate their experiences in the game accordingly.

While invoking prior experiences was a salient reaction of practitioners, students reacted in another salient manner – exercising reflection and using it to inform their future beliefs and behaviors. In other words, students are learning from the game where their behaviors lie relative to their beliefs and deciding how they may want to move forward as they prepare to enter industry. Davis and colleagues [58] describe the importance of learning reflection among engineering students to develop the professional skills needed in engineering. They provide evidence that repeated reflection supports professional skill development in engineering students, further emphasizing its importance in the engineering education landscape and validating Schön's [59] claims of the need for reflection among practicing engineers. Ultimately, we suspect this reaction of students that informs their future behaviors and beliefs is due, in part, to their limited industry experience. Students have fewer of these experiences to ground their beliefs and behaviors compared to practitioners and, as a result, engage in reflection to better understand the nuances behind their beliefs and behaviors.

The blame practitioners and students cast on the game's structure and its nature for causing some gaps is a similar response that scholars have found in their investigations regarding reactions to the IAT [41–43, 60] and tied into their criticisms of the game. In cases of the IAT and our work, the gaps were presented to individuals, and we suspect this may have contributed to blaming the game.

7. Limitations and Future Work

Several limitations with respect to this work exist and must be acknowledged. First, the boundaries posed on participants' responses in the game restricted the judgements they wanted to make. Many had discussed how this affected their actions and their desire to have more autonomy in the game. As a result, future work includes designing a game that allows for additional autonomy and subsequently assessing how participants respond to any belief-behavior gaps that arise. Second, the game did not allow equal prioritization of factors even though they were allowed during participants' initial beliefs interview which may have affected how belief-behavior gaps were depicted. To assess this limitation much like the first, future iterations of this game should allow for equal prioritization of factors to better give participants autonomy over their actions. In addition, we applied convenience sampling of practitioners as they were all part of the professional networks of various research team members. Future iterations may employ more randomized sampling of practitioners to obtain results that can be confidently generalized to the process safety practitioner population. Lastly, Author Bodnar played a key role in developing *CUP*, and our substantial investment in this project may lead to biases – our deep engagement with the game may have shaped our research outcomes and the perspectives presented in this work.

8. Conclusion

In this study, we compared the reactions of engineering practitioners and engineering students to gaps between their beliefs and simulated gameplay behaviors about the prioritization of competing factors in process safety judgments after playing a digital process safety game geared towards process safety in chemical engineering. Both engineering practitioners and students found the boundaries posed by the game limited their actions and was one of the causes of belief-behavior gaps. However, when such was not the case, practitioners were more likely to assess the realism of the scenarios posed in the game based on their prior experiences while students were more likely to become reflective of their belief-behavior gaps. In doing this, students sought out how their newfound insights may inform their future beliefs and behaviors. Ultimately, we suspect this difference in findings is due to the lack of industry-related prior experiences students have relative to practitioners.

References

1. P. Lappalainen, Communication as part of the engineering skills set, *Eur. J. Eng. Educ.*, **34**(2), pp. 123–129, May 2009.
2. A. Konak, S. Kulturel-Konak, G. E. Okudan Kremer and I. E. Esparragoza, Teamwork attitude, interest, and self-efficacy: Their implications for teaching teamwork skills to engineering students, in *2015 IEEE Frontiers in Education Conference (FIE)*, pp. 1–3, Oct. 2015.
3. H. J. Passow, Which ABET Competencies Do Engineering Graduates Find Most Important in their Work?, *J. Eng. Educ.*, **101**(1), pp. 95–118, 2012.
4. B. K. Jesiek, L. K. Newswander and M. Borrego, Engineering Education Research: Discipline, Community, or Field?, *J. Eng. Educ.*, **98**(1), pp. 39–52, 2009.

5. D. H. Jonassen, J. Strobel and C. B. Lee, Everyday Problem Solving in Engineering: Lessons for Engineering Educators, *J. Eng. Educ.*, **95**(2), pp. 139–151, 2006.
6. D. G. Ullman, Robust decision-making for engineering design, *J. Eng. Des.*, **12**(1), pp. 3–13, Mar. 2001.
7. D. H. Jonassen, Designing for decision making, *Educ. Technol. Res. Dev.*, **60**(2), pp. 341–359, Apr. 2012.
8. E. Godfrey and L. Parker, Mapping the Cultural Landscape in Engineering Education, *J. Eng. Educ.*, **99**(1), pp. 5–22, 2010.
9. A. Picon, Engineers and engineering history: problems and perspectives, *Hist. Technol.*, **20**(4), pp. 421–436, Dec. 2004.
10. W. Faulkner, 'Nuts and Bolts and People': Gender-Troubled Engineering Identities, *Soc. Stud. Sci.*, **37**(3), pp. 331–356, Jun. 2007.
11. A. L. Pawley, Universalized Narratives: Patterns in How Faculty Members Define 'Engineering,' *J. Eng. Educ.*, **98**(4), pp. 309–319, 2009.
12. W. Addis, *Structural engineering: The nature of theory and design*. Ellis Horwood Ltd., 1990.
13. E. Dringenberg, G. Guanes and A. Leonard, Student and Faculty Beliefs about Diverse Approaches to Engineering Design Decisions, *Stud. Eng. Educ.*, **2**(2), pp. 78–95, 2021.
14. E. P. Douglas, M. Koro-Ljungberg, N. J. McNeill, Z. T. Malcolm and D. J. Therriault, Moving beyond formulas and fixations: solving open-ended engineering problems, *Eur. J. Eng. Educ.*, **37**(6), pp. 627–651, Dec. 2012.
15. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey and L. J. Leifer, Engineering Design Thinking, Teaching, and Learning, *J. Eng. Educ.*, **94**(1), pp. 103–120, 2005.
16. M. H. Forbes, A. R. Bielefeldt, J. F. Sullivan and R. L. Littlejohn, Divergent Requirements for Technical and Non-Technical Coursework in Undergraduate Engineering Programs, *Int. J. Eng. Educ.*, **1**(A), pp. 162–174, 2017.
17. D. H. Jonassen, Instructional design models for well-structured and III-structured problem-solving learning outcomes, *Educ. Technol. Res. Dev.*, **45**(1), pp. 65–94, Mar. 1997, doi: 10.1007/BF02299613.
18. E. Dringenberg, A. Abell and G. Guanes, Decision Making in Engineering Capstone Design: Participants' Reactions to a Workshop about Diverse Types of Reasoning, *Int. J. Eng. Educ.*, **35**(6(B)), pp. 1907–1917, 2019.
19. L. L. Bucciarelli, *Designing Engineers*, MIT Press, 1994.
20. E. A. Cech and H. M. Sherick, Depoliticization and the Structure of Engineering Education, in *International Perspectives on Engineering Education: Engineering Education and Practice in Context*, vol. 1, S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, Eds., Cham: Springer International Publishing, pp. 203–216, 2015.
21. G. Downey and J. Lucena, When Students Resist: Ethnography of a Senior Design Experience in Engineering Education, *Int. J. Eng. Educ.*, **19**(1), pp. 168–176, 2003.
22. A. Leonard, G. Guanes and E. Dringenberg, Undergraduate students' beliefs about diverse approaches to making engineering design decisions: Exploring change during a capstone course, *Int. J. Technol. Des. Educ.*, **33**(5), pp. 1959–1989, Nov. 2023.
23. G. Guanes, A. Leonard and E. Dringenberg, Undergraduate students' espoused beliefs about different approaches to engineering design decisions, *J. Eng. Educ.*, **112**(4), pp. 938–962, 2023.
24. C. A. Roberts and S. M. Lord, Making Engineering Sociotechnical, in *2020 IEEE Frontiers in Education Conference (FIE)*, pp. 1–4, Oct. 2020
25. D. Kahneman, *Thinking, fast and slow*, Farrar, Straus and Giroux, 2011.
26. E. E. Miskioğlu, K. M. Martin, A. R. Carberry, C. Bolton and C. Aaron, "Is it Rocket Science or Brain Science? Developing an Approach to Measure Engineering Intuition," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: May 07, 2025. [Online]. Available: https://peer.asee.org/is-it-rocket-science-or-brain-science-developing-an-approach-to-measure-engineering-intuition
27. E. E. Miskioğlu, K. Martin and A. Carberry, The critical role of intuition in problem solving, in *Ways of Thinking in STEM-based Problem Solving*, Routledge, 2024.
28. K. E. Stanovich and R. F. West, Individual differences in reasoning: Implications for the rationality debate?, *Behav. Brain Sci.*, **23**(5), pp. 645–665, Oct. 2000.
29. E. E. Miskioğlu, C. Aaron, C. Bolton, K. M. Martin, M. Roth, S. M. Kavale and A. R. Carberry, Situating intuition in engineering practice, *J. Eng. Educ.*, **112**(2), pp. 418–444, 2023.
30. J. Strobel and R. (Celia) Pan, Compound Problem Solving: Insights from the Workplace for Engineering Education, *J. Prof. Issues Eng. Educ. Pract.*, **137**(4), pp. 215–222, Oct. 2011.
31. N. Canney and A. Bielefeldt, A framework for the development of social responsibility in engineers, *Int. J. Eng. Educ.*, **31**(1B), pp. 414–424, 2015.
32. T. Litzinger, L. R. Lattuca, R. Hadgraft and W. Newstetter, Engineering Education and the Development of Expertise, *J. Eng. Educ.*, **100**(1), pp. 123–150, 2011.
33. "U.S. Chemical Safety and Hazard Investigation Board | CSB." Accessed: Jul. 20, 2024. [Online]. Available: https://www.csb.gov/
34. Sphera, "Safety Report 2022," Sphera, 2022.
35. United States Chemical Safety and Hazard Investigation Board, "Final Investigation Report: Chevron Richmond Refinery #4 Crude Unit," Richmond, California, Jan. 2015.
36. M. H. Connors and P. W. Halligan, A cognitive account of belief: a tentative road map, *Front. Psychol.*, **5**, Feb. 2015.
37. A. G. Greenwald, The Totalitarian Ego: Fabrication and Revision of Personal History, *Am. Psychol.*, **35**(7), pp. 603–618, 1980.
38. A. C. T. Smith, *Cognitive Mechanisms of Belief Change*, London: Palgrave Macmillan UK, 2016.
39. J. Stransky, C. Ritz, E. Miskioğlu, C. A. Bodnar and E. Dringenberg, Key Methodological Considerations for Designing Research to Compare Beliefs and Behavior, *Eur. J. Eng. Educ.*, In Review.
40. G. Eysenbach and J. E. Till, Ethical issues in qualitative research on internet communities, *BMJ*, **323**(7321), pp. 1103–1105, Nov. 2001.
41. S. Schlachter and S. Rolf, Using the IAT: how do individuals respond to their results?, *Int. J. Soc. Res. Methodol.*, **20**(1), pp. 77–92, Jan. 2017.
42. J. L. Howell, S. E. Gaither and K. A. Ratliff, Caught in the Middle: Defensive Responses to IAT Feedback Among Whites, Blacks, and Biracial Black/Whites, *Soc. Psychol. Personal. Sci.*, **6**(4), pp. 373–381, May 2015.
43. J. L. Howell, L. Redford, G. Pogge and K. A. Ratliff, Defensive Responding to IAT Feedback, *Soc. Cogn.*, **35**(5), pp. 520–562, Oct. 2017.

44. J. L. Howell, B. Collisson, L. Crysel, C. O. Garrido, S. M. Newell, C. A. Cottrell, C. T. Smith, J. A. Shepperd, Managing the Threat of Impending Implicit Attitude Feedback, *Soc. Psychol. Personal. Sci.*, **4**(6), pp. 714–720, Nov. 2013.
45. J. Stransky, "Exploring Senior Chemical Engineering Students' Approach to Process Safety Decision Making," *Theses Diss.*, May 2023, [Online]. Available: https://rdw.rowan.edu/etd/3122
46. J. Stransky, C. Hill, R. J. McErlean, J. Willetts, L. Bassett, D. D. Anastasio, D. D. Burkey, M. Cooper and C. Bodnar, "Impact of Immersive Training on Senior Chemical Engineering Students' Prioritization of Process Safety Decision Criteria," presented at the *2021 ASEE Virtual Annual Conference* Content Access, Jul. 2021.
47. "Home | Contents Under Pressure." Accessed: Oct. 19, 2024. [Online]. Available: https://contentsunderpressure.engineering.uconn.edu/
48. J. Saldana, *The Coding Manual for Qualitative Researchers*, 4th ed. SAGE Publications Ltd., 2021.
49. M. B. Miles, A. M. Huberman and J. Saldana, *Qualitative data analysis: a methods sourcebook*, 4th edition, Thousand Oaks, California: SAGE Publications, Inc., 2020.
50. J. Saldana and M. Omasta, *Qualitative Research: Analyzing Life*, 1st ed. SAGE Publications, Inc., 2017.
51. B. Glaser and A. L. Strauss, *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Mill Valley, California: Sociology Press, 1967.
52. K. Charmaz, *Constructing Grounded Theory*, 2nd ed. SAGE Publications Ltd., 2014.
53. J. Walther, N. W. Sochacka and N. N. Kellam, Quality in Interpretive Engineering Education Research: Reflections on an Example Study, *J. Eng. Educ.*, **102**(4), pp. 626–659, 2013.
54. J. Walther and N. Sochacka, Qualifying qualitative research quality (The Q3 project): An interactive discourse around research quality in interpretive approaches to engineering education research, in *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, pp. 1–4, Oct. 2014.
55. M. M. Richter and R. O. Weber, Case-Based Reasoning: A Textbook. Berlin, Heidelberg: Springer, 2013.
56. E. Dane, Reconsidering the Trade-off Between Expertise and Flexibility: a Cognitive Entrenchment Perspective, *Acad. Manage. Rev.*, **35**(4), pp. 579–603, Oct. 2010.
57. D. Stone and S. Heen, *Thanks for the Feedback: The Science and Art of Receiving Feedback Well*. New York, NY: Viking Penguin, 2015.
58. D. Davis, M. Trevisan, P. Leiffer, J. McCormack, S. Beyerlein, M. J. Khan and P. Brackin, "Reflection and Metacognition in Engineering Practice," in *Using Reflection and Metacognition to Improve Student Learning: Across the Disciplines, Across the Academy*, 1st ed., M. Kaplan, N. Silver, D. LaVaque-Manty and D. Meizlish, Eds., in New Pedagogies and Practices for Teaching in Higher Education Series, Sterling, Virginia: Stylus Publishing, LLC, pp. 78–103, 2013.
59. D. A. Schön, *The Reflective Practitioner: How Professionals Think in Action*, London: Routledge, 2017.
60. J. L. Howell and K. A. Ratliff, Not your average bigot: The better-than-average effect and defensive responding to Implicit Association Test feedback, *Br. J. Soc. Psychol.*, **56**(1), pp. 125–145, 2017.

Sherri Youssef is a PhD candidate in the Department of Engineering Education at The Ohio State University. Her research interests include the role of belongingness on the motivation of engineering students to persist through their degree programs and coursework. She is also interested in the lived experiences of engineering students on non-traditional pathways and how their experiences inform their motivation to persist. She has a BS in Materials Science and Engineering and an MS in Mechanical Engineering from The Ohio State University.

Amanda Singer Nault is a PhD candidate in the Department of Engineering Education at The Ohio State University. She holds a BS and MS in Environmental Engineering from Michigan Technological University ('19, '21). Her research focuses on the experiences of students who begin their engineering education through alternative (i.e., non-four-year institution) pathways, with an emphasis on those starting at regional campuses. She is also interested in using mixed methods approaches to explore how the first-year engineering experience at regional campuses influences the development of students' engineering identities.

Cayla Ritz, PhD, finished her graduate program at Rowan University and currently holds a mechanical design engineer position at a mid-size MEP engineering firm. She holds a BS and MS in mechanical engineering from the same institution. Her research focuses on how story-driven games can be used to help engineering students understand how they may make decisions in professional engineering roles. She is particularly interested in how engineers make decisions in public welfare, community/environmental safety, and social contexts.

Brittany Butler-Morton is currently pursuing a PhD in Engineering Education in the Experiential Engineering Education department at Rowan University. Her research focuses on the differences in the way chemical engineering students and industry professionals approach process safety judgments, and developing instructional methods that expose students to the contexts surrounding judgments made in process safety incidents. She is specifically interested in identifying how the Theory-to-Practice gap may be manifesting in process safety based on the situational elements, perspectives, and emotional involvement students and practitioners use when making judgments.

Emily Dringinberg, PhD, is an Associate Professor in the Department of Engineering Education at The Ohio State University. She holds a BS in Mechanical Engineering (Kansas State '08), an MS in Industrial Engineering (Purdue '14) and a PhD in Engineering Education. Her current career purpose is to learn about and reveal beliefs that are widely-held as an implicit result of our socialization within systems of oppression so that she can embolden others to reflect on their assumptions and advance equity in their own ways.

Cheryl A. Bodnar, PhD, is a Professor in the Engineering Education Department at The Ohio State University. 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.

Elif Eda Miskioğlu, PhD, is an Associate Professor in the Department of Chemical Engineering at Bucknell University. As a chemical engineering educator and engineering education scholar she aims to leverage her roles to generate new knowledge on expertise development and problem solving reflecting current engineering practice and bring research-informed initiatives into the classroom and profession. She is particularly interested in the expert problem-solving skill of engineering intuition.