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What do Practicing Engineers say about Stakeholder Exploration? Expanding Understanding of Divergent Exploration in Design*

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Engaging stakeholders is a key part of successful engineering design projects. The set of stakeholders with whom engineers engage influences engineering outcomes, where divergent thinking can support a collection of broad perspectives to guide the work. In design processes, divergent thinking is used to consider a variety of solutions, problem understandings, and process pathways, as well as a variety of perspectives of both internal and external stakeholders. Business management literature describes stakeholder identification methods and engineering literature describes stakeholder engagement approaches, yet engineering literature has not addressed barriers to and supports of divergent thinking about potential stakeholders within practitioners' disciplinary, work, and personal contexts. As part of a larger project on divergent thinking, this paper focuses on engineering practitioner barriers to and facilitators of divergent exploration of stakeholders. In our study, we interviewed twenty professional engineers about their divergent thinking about stakeholder perspectives in one of their engineering projects. The data revealed eleven barriers to and eight facilitators of divergent exploration of stakeholders as well as reasons the practitioners valued stakeholders. Our findings advance research on engineers' experiences with divergent thinking about stakeholders and suggest ways to leverage professionals' experiences in early-career design education to assist engineers as they learn to consider and collect stakeholder perspectives.

Keywords: divergent thinking; stakeholder exploration; engineering practitioners

1. Introduction

Engaging stakeholders is key to the success of engineering design projects. Stakeholders are often defined as anyone who could impact or be impacted by the implementation of a design [1]. Human-centered design processes in particular emphasize the importance of accounting for stakeholder perspectives during design work [2, 3]. Stakeholders can provide information to improve engineers' understanding of problems and increase appreciation of a solution's implications [4]. One recommended practice is to engage with a broad range of stakeholders in order to better understand the problem, anticipate possible solutions, and reduce the potential of an ineffective or harmful solution [5, 6]. Before engineers can engage with stakeholders, they must first identify those stakeholders. Limited divergent thinking about who those stakeholders include can lead to unsuccessful design outcomes.

Business management literature has described approaches for identifying key organizational stakeholders [e.g, 7], but this research has not focused on engineering-specific problem solving. Studies have also described challenges practitioners face in successfully exploring stakeholders in specific fields. For example, a study of software professionals found that they struggled to identify indirect stakeholders, in part because of a cultural emphasis on technology development over stakeholder identification in their domain [8]. A case study of infrastructure projects found that during stakeholder identification, practitioners failed to have a consistent definition of who 'counts' as a stakeholder and had weak understandings of the interactions (positive and negative) of a project with its stakeholders [9]. Engineering research has described multiple approaches engineering designers use to *engage* with stakeholders that support rich information gathering [10–12]. However, while some literature highlights cases where engineers overlooked important stakeholders [13–15], there remains a gap in understanding the

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factors that either support or impede engineers in considering a range of stakeholders.

As part of a larger project investigating divergent thinking, we interviewed 20 practicing engineers working on a variety of engineering projects in industry settings about their experiences during a specific past project where they engaged in divergent thinking. In this study, we specifically examined their experiences with divergent exploration of stakeholders. Our goal was to understand how practitioners in the field described the barriers and facilitators of divergent exploration of stakeholders as well if they saw value in considering stakeholders. Understanding how practicing engineers succeeded (or not) in stakeholder exploration can guide strategies used in both design practice and education. In engineering design education, the findings can guide early career education to support intentional use of divergent exploration in recognizing and gathering diverse stakeholder perspectives.

2. Background

We define stakeholder exploration as divergent thinking about who stakeholders of a project could be. *Divergent thinking* is the consideration of multiple alternatives that occurs before narrowing down which options to pursue [16, 17]. In practice, engineers often associate divergent thinking with idea generation (such as by brainstorming) and engineering design education textbooks similarly emphasize exploration during idea generation [18–20]. However, divergent thinking can benefit engineering design and problem solving more broadly in many other ways; for example, engineers can explore a diverse set of sources in their contextual research, identify alternative methods to work towards solutions, or seek to understand a problem from multiple stakeholder perspectives [21–23]. Literature also uses the language of *stakeholder identification* to describe the thinking about who may impact or be impacted by a design, although much literature appears to include both the exploration *and management* of selected stakeholders in its definition. Stakeholder exploration is also distinct from stakeholder engagement, which is the act of gathering information from stakeholders.

Literature on stakeholder *engagement* in engineering is substantial. Engaging with stakeholders is a key part of engineering design, demonstrated to lead to a more holistic understanding of the people impacted by design decisions and more contextually appropriate designs [3, 24]. Engineers may conduct in-depth interviews with stakeholder [25, 26], leverage focus groups with intended users [27], conduct observations of stakeholders within their contexts, [28, 29]; or engage stakeholders as design partners during co-design sessions [30]. Intentional engagement with stakeholders has been shown to support empathy building for people impacted by engineering decisions [31–33]. Stakeholder engagement can take place across engineering design processes, from problem scoping to concept generation to development and scaling [34].

Literature on stakeholder *exploration* in engineering is limited. Of the existing literature attending to engineering consideration of stakeholders, studies of divergent thinking have shown that which stakeholders were considered had impacts on the ways that problems were understood and the types of solutions generated. For example, in a study by Studer and colleagues [35], one pattern of problem exploration involved expanding the primary stakeholder group to broaden the problem, leading to a different view of the problem to explore. In another study, Murray and colleagues [36] identified a strategy for divergence in exploring problems by identifying various subgroups *within* a primary stakeholder group. This intentional focus on divergent thinking about the primary stakeholder group probed the problem at a deeper level to identify more specific views of the problem. Studies of idea generation have also shown that what stakeholder, if any, designers are considering as they suggest ideas, and the extent of that consideration, impacts the types of solutions considered [37-39]. Without divergent thinking of who the stakeholders could include, problem understandings and solution options are more narrow.

Multiple approaches have been described to identify relevant stakeholders, most of which are suggested outside of engineering problem solving contexts. For example, a seminal paper on stakeholder identification theory emphasized how managers prioritize stakeholders with the greatest power, legitimacy, and urgent needs in an organization [40]. In software engineering, StakeRare is a process of building a social network of stakeholders by leveraging the snowball recommendations of already-identified stakeholders to identify others [41]. The process then uses 'collaborative filtering' to prioritize stakeholders and their requirements. One study with ergonomics and human factors students tested the Change Agent Infrastructure (CHAI) stakeholder identification method [42]. The method proposes eight roles stakeholders may take, providing guidance for students while allowing for examination of potential interactions between stakeholders and the design. There is extensive research on stakeholder identification in project management literature, leading to methods such as the Stakeholder Circle, where project man-

agers visualize the stakeholders' power and influence on the project [43].

Literature has shown that stakeholder exploration can be challenging for practitioners. One study found that engineers struggled to identify 'indirect' stakeholders with little influence on technology development, even though indirect users often experience the effects of design implementations [8]. Watkins and Denney [44] conducted interviews with 71 project managers across domains about their experiences with stakeholder planning, identification, and engagement. They found that managers emphasized the importance of early stakeholder identification, but that many struggled to describe specific methods or strategies in doing so. A different study on project managers reported that some managers struggled to define the project boundaries, and therefore found it difficult to know who was a relevant stakeholder [45].

Some literature has suggested multiple factors that might influence stakeholder exploration. For example, one's organizational perspective (e.g., organization-centric, issue-centric, or supply-chain-centric) can impact the types of stakeholders identified [46]. The size of the business has also been shown to have an influence on stakeholder exploration, with the claim that more stakeholders are engaged with as small businesses can have greater "social closeness" [47]. Stakeholder exploration can also be impacted by the usability of stakeholder exploration tools. For example, Pacheco and Garcia [48] found that existing guides in software development lacked the structure and consistency needed to support engineers in following the recommended exploration practices. While some methods for stakeholder identification exist, it is not clear in the literature to what extent these are taken up by engineering practitioners in their projects nor is it clear what other factors in their disciplinary, organizational, and personal contexts might influence the extent to which they engage in stakeholder exploration.

3. Method

This inquiry was part of a larger study about professional mechanical engineers' experiences with divergent thinking. In this paper we present a subset of the data and their analysis guided by the following research questions:

(1) How do practitioners describe the value of exploring stakeholders in engineering projects?
(2) What barriers do practitioners perceive to stakeholder exploration?
(3) What facilitators do practitioners perceive to stakeholder exploration?

3.1 Participants

Participants included 11 men and 9 women, all U.S. mechanical engineers. Participants identified their race and/or ethnicity as white (11), Black (5), Latinx (1), Hispanic (1), Southeast Asian (1), and Guyanese (1). Their engineering practice experience ranged from 1.5 to 38 years, averaging 12.4 years (SD = 10.7). Participants worked in engineering industries including automotive, electric vehicle, consumer products, biomedical, human factors, aerospace, commercial trucking, defense, locomotive, energy, and various research and development areas. Participants were identified and recruited using the authors' professional networks, local engineering associations, and snowball sampling from participants.

3.2 Data Collection

We conducted individual semi-structured interviews with each participant. Semi-structured individual interviews allow for a standard set of questions across participants while also allowing flexibility for deep dives to elicit specific participant experiences as necessary [49].

Before the interview, participants were asked to recall a specific experience during a past project where they practiced divergent thinking in their design process. We used the language of exploration to make our questions on divergent thinking accessible to participants: "We're interested in open-ended engineering project experiences where you explored multiple options or perspectives in one or more aspects of the project." We proposed five areas of potential exploration: including problem understanding, researching stakeholders, problem solving approaches, types of solutions, and project implications. We defined these areas of potential exploration based on common activities during engineering problem-solving processes [19] and an iterative protocol development process (described further by Clancy and colleagues [50]). We explicitly requested participants consider both successful and unsuccessful exploration during projects.

Each interview lasted about 90 minutes and was conducted virtually with audio recording. First, participants described the "big picture" of the past project they selected to discuss, along with its timeline, goals, and constraints. Each participant selected which areas of divergent exploration to discuss and answered the following questions: (1) What did you do? (2) How did you decide to do that? (3) What alternative options did you explore? (4) How did you know you had explored enough? (5) What alternatives did you not explore? (6) Why did you not explore those alternatives? (7) How successful were you at exploring? During inter-

views, we used follow-up questions to probe for clarification, additional depth, and meaning.

The interview protocol was developed based on recommended practices for semi-structured interviews [51, 52], prior author experience conducting concrete experience-based interviews with practitioners, and pilot testing with practitioners not in the study. The protocol questions, sequence, and language were revised following an iterative protocol development process, as described by Clancy and colleagues [50].

3.3 Data Analysis

After transcribing the 20 interviews, two authors identified interview excerpts related specifically to stakeholder exploration. While we provided the opportunity for all participants to discuss stakeholder exploration in the interview protocol, we found that participants discussed stakeholders across the entirety of the interviews, not only when specifically prompted to do so. Thus, excerpts on stakeholder exploration emerged across all areas of all 20 interviews. A few excerpts mentioning "stakeholders" appeared unrelated to exploration processes and were excluded from the analysis.

The analysis began with emergent identification of themes about stakeholders among the 229 excerpts across the 20 participants. These themes were identified by two coders working independently, and then refined through discussion. We grouped the themes into lists representing the values participants expressed for stakeholders, the factors from the data that supported participants in exploring a diverse set of stakeholders, and the factors that hindered participants from exploring a diverse set of stakeholders. Following recommended practices for thematic analysis [53], we iteratively revised descriptions of the identified themes for clarity through multiple reviews of the examples in each.

4. Findings

4.1 How does Exploring Stakeholders Improve Engineering Projects?

While the focus of this study was on barriers and facilitators to divergent thinking about stakeholders, we also report findings from participants about the value they saw in engaging stakeholders. These insights demonstrate in part that the barriers to divergent thinking about stakeholders were not necessarily rooted in practitioners' not valuing stakeholders in their engineering processes. Practitioners described stakeholder exploration as valuable to their engineering processes. In their past projects, divergent exploration of stakeholders led to better understandings of problems, improved problem-solving processes, risk mitigation, and validation of decisions. These gains led practitioners to talk about stakeholder exploration as a key to their projects' success.

(1) Exploring stakeholders *improves understanding* of the problem.

Participants found that exploring stakeholders led to a better understanding of the problems they were working to solve. By engaging with various design engineers, one participant was able to build their knowledge by consulting the people with the most topical expertise:

> "I really communicated with my design engineers . . . who knew the parts the best. I needed to understand our capabilities. What can we do to these hoses? What can these hoses take? I think I was very good at understanding the problem and checking off all my boxes of what is the problem." (P19)

(2) Exploring stakeholders *improves the problem-solving process.*

Participants used stakeholder exploration as a method to more effectively solve problems. One participant saw stakeholder exploration as a way to bring together more expertise, recognizing that one person would not have all the answers:

> "I don't know the product, so to speak. So I don't even know how to explore the options, you know? And so literally the first thing I do is find out as many stakeholders as possible in the process. And I just pull them all together in a meeting and force them to talk. It's less about me exploring the diverse options in this case . . . I'm sort of pulling diverse people together to explore the options. And that's the best that I can do in helping them problem solve." (P04)

(3) Exploring stakeholders helps *mitigate risk.*

Many participants described that exploring a diverse set of stakeholders mitigates risks in engineering problem solving. One participant described how engaging the right people in the early stages allowed her to ensure she was meeting the needs of all those involved in the project, minimizing the chance that she would miss a key aspect of the project:

> "By doing my homework upfront in tying in with the key stakeholders, we really assessed to make sure that we had everything covered from program kick off through project design, project tests, applications engineering, and then actual customer install on-site, right? So I think by engaging all of those right people along the way, we minimized any negative ramifications." (P08)

(4) Exploring stakeholders *validates decisions* and increases confidence.

Multiple participants leveraged stakeholder exploration as a way to gain confidence in the

engineering decisions they made. Participants felt that consulting various project stakeholders allowed them to further validate that their decisions were the right ones for the project:

> "Taking into account so many things and just working with a bunch of people from different backgrounds, so like engineers, CAD designers, FEA people, test engineers . . . We got to a point where it was like, you can't really think of anything else to do to keep analyzing the part. So that gives you a lot of confidence." (P05)

Participants described these four different ways that engaging with stakeholders supported their engineering projects across different stages of their engineering work.

4.2 What Barriers do Practitioners Perceive to Stakeholder Exploration?

Participants described varied circumstances that prevented them from more fully exploring a diverse set of stakeholders: (1) convergence dominance, (2) difficulty managing multiple perspectives, (3) fear of failure (4) fear of increasing risk, (5) in-house expertise, (6) lack of knowledge or clarity, (7) leadership divestment, (8) logistics of exploration, (9) narrow focus, (10) silo organization structure, and (11) uncertainty about exploration process. Each barrier is defined with two participant examples in Table 1.

Participant comments illustrated that not having an established process to direct stakeholder exploration often led to little (or unhelpful) exploration. Further, the perceived difficulty of managing multiple perspectives prevented participants from considering diverse perspectives at all. Similarly, some participants reported that their organizations had no process in place nor even *language* to describe alternatives, making it difficult for individual participants to prioritize exploration.

Although participants valued stakeholder exploration, they also described tensions with its practice, suggesting participants may need additional training or support. Many participants perceived stakeholder exploration as a loss of time and resources, or other risks they were unwilling to take on (e.g., brand-endangering product failures). The perception of risk contrasted participants' previously stated descriptions of benefits of stakeholder exploration, as risk mitigation influenced their approaches, indicating a tension between a known benefit and managing potential risk. Relatedly, many participants did not more fully explore stakeholders because they did not want the perceived social risk to fail or be embarrassed in front of other coworkers, reported more often by young, women, and minoritized engineering participants.

Knowledge acquisition or lack thereof appeared to impact stakeholder exploration. When participants held a narrow project focus, meaning they did not engage with nor understand the broader system in which engineering problem solving took place, they failed to engage with stakeholders in the broader project context. A lack of topical knowledge or project clarity prevented divergent exploration of stakeholders due to lack of time and resources to both choose and engage with stakeholders. Relatedly, on multiple occasions participants described how one expert opinion halted exploration of other stakeholders with potential relevance.

Some organizational structures made it challenging to divergently consider stakeholders. Participants felt that the partitioning between engineering teams made it challenging to access expertise in other groups. Similarly, organizations that failed to support engineers in coordinating the logistics of stakeholder exploration took time away from participants' abilities to actually engage with stakeholders. Finally, participants perceived that company management limited or completely halted stakeholder exploration by not prioritizing the time and resources needed for it.

4.3 What Facilitators do Practitioners Perceive to Stakeholder Exploration?

Participants described many circumstances that seemed to facilitate and encourage broad stakeholder exploration: (1) curiosity, (2) designated 'exploratory' roles or checkpoints, (3) desire for innovation, (4) leadership investment, (5) novelty, (6) systems thinking, and (7) team collaboration, and (8) team diversity. Each facilitator is defined and illustrated through participant examples shown in Table 2.

Some of the facilitators of stakeholder exploration related to organizational structure, some to inter- or intra-personal dynamics, and others to the individual drive of engineers in prioritizing exploration. Newness of technology or limited expertise was perceived to increase exploration through collecting new knowledge rather than relying on previous standard practices. Building diverse teams was often reported as a method for exploring diverse perspectives. Positive team dynamics including taking initiative on the work was perceived to encourage stakeholder exploration. Curiosity by teams or individuals was perceived to be able to drive stakeholder exploration. Similarly, engineers who prioritized stakeholder exploration were influential in facilitating exploration. Systems thinking, or understanding the broader project context, was also perceived as helpful to engineers in identifying a broad set of stakeholders. At an organizational level, creating specific roles or checkpoints with a diverse set of people to evaluate

Table 1. Participants' descriptions of barriers to stakeholder exploration

Barrier to stakeholder exploration	Participant descriptions of barriers
Convergence dominance: Cultural norms that inhibit divergence	"I would always ask the German, what is the plural form of the word 'answer'"? And they go, "nobody uses that." There's only one answer in German, right?" (P07) "Not anything bad between me and my manager, but old school manufacturing, they don't want to try anything new, so I didn't want too much of his input and feedback . . . so I left him on the outside of [the project]." (P19)
Difficulty managing: Overwhelmed by the prospect of multiple diverging perspectives	"Not having so many stakeholders because then you start to get octopus arms and you get pulled in all types of different directions." (P18) "I suppose that if there were too many stakeholders, there would be too many changes or too much input, so to speak." (P14)
Fear of failure: Potential negative social or professional consequences	"Trying to not sound stupid in front of, asking some of the other question between your coworkers because me being a girl from a different country, I was one of the youngest during that time period for that project." (P16) "I didn't want other people to think I didn't know what I was doing . . . I wanted to learn everything on my own and not sound stupid." (P17)
Fear of increasing risk: Responsibility for endangering project success	"We were limited in our scope by a handful of reputable recognized suppliers. So for risk mitigation, we didn't have the whole world to choose from because it was new technology. It's a brand-endangering product. You don't put it into the hands of a new partner. You choose a tried and true partner. Those partners work with only certain material limitations." (P02)
In-house expertise: Relying on limited internal sources for information	"I think it maybe kept exploration a lot more internal because I had someone so close to me who sort of maybe was an expert in it. So I could just really use that one source to learn everything I needed to know." (P11) "This guy has like invented 100 things and I have a lot of respect for him. So I think that it definitely was, 'Oh, if Pete thinks it's a good idea, then it's a good idea.'" (P12)
Lack of knowledge or clarity: Unknown project boundaries and limited domain knowledge	"When the problems are very complex and the scope is not defined easily, it gets more difficult because I am not a subject matter expert. I am only a systems engineer, so it's like I only know what I know." (P20) "Identifying stakeholders is a lot less black and white than knowing you have all your variables filled in your equation or things like that . . . . I think it would be really hard to know where the influence of any project stops." (P11)
Leadership divestment: Managers preventing or deprioritizing exploration	"I would have liked to have considered the end-user more, but I got some pushback on that one . . . I would have liked to have considered more stakeholders' interests, but was prevented from doing so." (P06) "But if [managers] think it's going to take away time from me working on a project, they might be like, 'Okay, can you just do it after?' It's like, no, I need it now." (P13)
Logistics of exploration: Organization and communication required for stakeholder exploration	"I think we saw like three or four hospitals, but if someone had set up like six initially and they told us like, 'This is going to be a diverse representation of your sample set. This is all you need.' Then we would be better off because we would have more time to gather that information, whereas we were really struggling to get those three or four visits booked." (P09) "If I don't feel like they have as much input or as much riding on this, is it worth the effort of detailing them out and thinking about them if it's not affecting the project as much as some of my other more key stakeholders?" (P11)
Narrow focus: Limited perspective of the project system	"At the end, you are involved in your small world in the planning side and you don't look outside." (P16) "A lot of the stakeholders that I did not identify from the start was the battery side modules . . . And so a lot of this comes down to ignorance, I think. So I think in totally understanding, I knew the scope but the project was larger than the scope." (P20)
Silo organization structure: Divided teams with limited or no communication	"The difficult part is like even that I have other peers in quality, you never get to work with them." (P16) "Once I released at drawing, supply chain would take it over and do their job. They would just handle it. It would get made and it'll go down the line. So it was kind of a "throw it over the wall and forget about it" type process." (P01)
Uncertainty about exploration process: Limited or no described method to facilitate exploration	"I can't say that I made a conscious decision on that [exploring stakeholders]. Mainly, it came down to, I had a problem I couldn't solve. Go figure it out." (P01) "Well, I don't know if I decided. I think that's generally who are always considered the stakeholders. You have the person who's paying for it and if you're a sub, then the ultimate group who's paying for it and then there's the end-user." (P06)

stakeholder exploration was perceived to encourage and validate it. Finally, if someone in a leadership position requested divergent exploration, more time and resources were devoted towards it.

5. Discussion

Practitioners described 11 distinct barriers to stakeholder exploration ranging from environmental factors like convergent cultural norms to individual traits like a lack of domain knowledge. We also identified 8 distinct facilitators that supported practitioners in exploring stakeholders, ranging from internal team composition and attitudes to organizational processes and management. We also found that the professional engineers in our study valued divergent exploration of stakeholders for a variety of reasons. Recognizing that practitioners valued

Table 2. Participants' descriptions of facilitators for stakeholder exploration

Facilitator of stakeholder exploration	Participant descriptions of facilitators
Curiosity: Individual mindsets to seek out diverse perspectives	"During our visits we were really open-minded and . . . we gathered so much information . . . My colleague and I were both really curious." (P09) "Always my advice is to humble yourself. I have no problems whatsoever talking to the injection molding supplier because they are experts at injection molding and tell me how to improve the design of this part." (P01)
Designated roles: 'Exploratory' roles or checkpoints	"I think the buy-off of the systems-level people. Yeah. I think it's kind of their role to understand if there's any other people that need to be consulted or anything like that." (P10) "I couldn't necessarily move forward unless we gave the green light on who I saw as the key stakeholders." (P18)
Desire for innovation: Drive to investigate and improve technology	"I think my personality really pushes the divergence side a little bit more, which is why I've run into some frustrations with previous projects where this is the way we have to do it. But why can't we try and do it better?" (P12) "Being open to when someone asks you hard questions, being open to saying, "I don't know, but I'll investigate" and investigating . . . They're asking because they've had experiences where things didn't go their way and they know that." (P05)
Leadership investment: Management prioritizing and dedicating resources	"When they come back to you a third time for the same thing you've been working on that you didn't think had a lot of weight to it. And now they're like name dropping a vice president or a director. You're like, 'oh, okay, got it, got it. Upper level management wants to know about this? This must be something important.'" (P13) "I think that some parts of my environment definitely helped me [explore]. For example, my manager has a PhD so he comes from a very academic background, which I think leans a little bit more towards like doing a lot of research from different sources." (P11)
Novelty of domain: Newness of problem or solution space requiring engagement with experts	"I'm not a chemist. That was actually probably my weakest subject going through school. I much preferred physics and materials and things like that than chemistry itself. So I was always down on the line talking to the chemists. The people that actually ran the chemistry line, 'Oh, hey, what can I use? Will this work?' Because they are the subject matter experts when it comes to the actual dipping process. Obviously worked with people like supply chain. 'Is this stuff even possible?' Worked with manufacturing. 'Can you make it?'" (P01) "This is something I don't know. It's not my right area. I gotta ask XYZ engineer because he's an expert in it. Right?" (P17)
Systems thinking: Broad view facilitates knowledge of all impacted	"People have different vantage points and I mean, even if you're on a manufacturing line, the person that's in front of you, behind you, to left, to the right, whatever that is, you're a customer to each other. You're a teammate to each other. From someone that's sitting in accounting and finance to someone that sitting in human resources. These are all part of a team and everybody plays their part. So for me it's just always been looking at the larger picture. Sometimes you need to step back and look at the big picture." (P15) "How did we determine that we had enough stakeholders? I think by considering the lifecycle of the part itself, or the lifecycle of the problem, right? We were trying to solve a problem with a product, everyone that will both touch it and interface with it or has to deal with it has to be represented in some way." (P02)
Team collaboration: Positive environment supports communication	"When you're working with a team that's dedicated and focused, you don't mind it. It's something you can really latch onto and you get energized by it actually." (P07) "For myself, I knew everybody in the plant. And then of course we knew the plant that we ship things to. The design engineer knew the people at the plant that were making the vehicle, as well as we both were core team members. So we knew the program manager, the sales, and all those . . . It was a small enough plant that I got to know everyone quickly. When you work in that environment, you get to know who does what." (P15)
Team diversity: Diversity of experiences and backgrounds informing decisions	"That team was successful. I think we had a wide range of experiences coming in. So there were four or five of us primarily working on the project of various ages. Mexican, French, American. People from not just the automotive but from other areas where people come and various. . . . Everybody was coming in with a different schema and being able to be collaborative." (P02) "Sitting down with all my teammates and looking at the problem and everyone coming up with ideas or things that should be looked into that we should be considering. So just having multiple people with their own set of experiences. That's the best. I mean, it's essentially diversity of thought, right? Like just having multiple points of view and having people [who] have solved other problems and bringing that experience with them." (P05)

stakeholder exploration yet they still experienced many barriers is indicative that there are improvements needed from education and practice perspectives to support divergent thinking in stakeholder consideration.

Practitioners reported that exploration of stakeholders improves problem understanding and their problem-solving process and helps to mitigate risk, resulting in greater confidence about decisions. The stated values expand our understanding of why it is so important for engineers to divergently explore stakeholders. The values echo literature from related fields. For example, stakeholder exploration has been shown to be valuable in supporting responsible decision-making for policymakers, especially in avoiding unintended consequences

[46]. Sippl and colleagues [54] described how planning technical changes in designs requires identifying all relevant stakeholders to ensure effective project outcomes. Stakeholder engagement has been shown to be an effective part of gathering contextual information [55], a goal related to improving problem understanding. Practitioners described leveraging stakeholder exploration as a means to improve other aspects of their problem-solving process, which has not been previously described in literature. Supporting stakeholder exploration, therefore, has the potential to improve problem-solving more broadly.

The impact of the organizational environment on stakeholder exploration suggests that some environments are more conducive to supporting divergent exploration than others. An organization that prioritizes more diverse teams or encourages taking on perceived added risks may be more successful in facilitating divergent exploration. Alternatively, an organization relying solely on in-house expertise or one without a systems perspective may struggle in facilitating divergent exploration of stakeholders. Business management literature described how some aspects of an organization, such as size and social proximity, can influence practitioners' exploration of stakeholders [47, 56]. Our work contributes to a more nuanced understanding of specific organizational characteristics that can support or inhibit stakeholder exploration in engineering.

Practitioners described that the perspectives and influence of their leadership affected their ability to explore stakeholders. While leadership divestment reportedly stopped stakeholder exploration, leaders who emphasized the importance of exploration (and provided resources for it) facilitated its practice during projects. These findings align with stakeholder identification and salience theory from business management literature; Mitchell and colleagues [40] described that managers' perceptions of stakeholder importance was a key factor in determining whether or not to account for that stakeholder's perspective. Wood and colleagues [57] further emphasized that regardless of stakeholders' *actual* relevance to a project, it is their *perceived* relevance by managers that drives identification and engagement. Engineering managers would benefit from evaluating how they are encouraging or preventing engineers from conducting beneficial exploration, especially in early stages of projects.

Practitioners described fears of risk and failure as barring their exploration of stakeholders. The fears of increasing risk or failure have been shown to have complicated effects in other domains. In entrepreneurship, for example, fears of risk or failure have been described as producing both negative limiting consequences and helpful motivation, all seen as part of the 'entrepreneurial journey' [58]. The fear of social failure or embarrassment practitioners described as limiting divergent exploration could relate to their psychological safety in the workplace. There is little debate that psychological safety in the workplace promotes better team communication, learning, and innovation [59, 60]. Multiple women and minoritized engineers in our study described overcoming a fear of 'sounding stupid,' describing key events where their ability to push past the fear improved outcomes. Prior work identified that people with minoritized racial and gender identities are more likely to experience the work performance and retention consequences of a lack of psychological safety [61, 62]. These patterns suggest that engineering teams would benefit from prioritizing psychological safety, especially when seeking to promote divergent exploration of many, diverse perspectives.

Notably missing from the practitioner interviews was any mention of explicit strategies to explore stakeholders. Further, the lack of strategies appeared to be a barrier for practitioners. Practitioners often described feeling overwhelmed by too many stakeholders, suggesting uncertainty about managing exploration of alternatives. Many practitioners lacked strategies to ensure they had considered enough stakeholders to make decisions. The lack of accessible approaches for exploring stakeholders led to a variety of problems. For example, one practitioner's lack of strategy led to missing early engagement with a key stakeholder group. This finding is consistent with literature showing that designers have struggled to navigate stakeholder perspectives that do not align with one another, causing designers to limit or stop stakeholders engagement altogether [63–65]. The impact of not having approaches for divergent thinking about stakeholders suggests that establishing guiding principles for processes may help facilitate exploration of stakeholders throughout engineering project work.

Practitioners described that taking on a systems perspective was key in building their knowledge of all the people who may be impacted by their decisions. In business management literature, experts suggested that all stakeholder work should be undertaken with a comprehensive systems approach within which stakeholder exploration is a subsystem [66]. Within engineering, multiple sources call for an emphasis on systems thinking [67, 68]. Past engineering failures indicate that engineers must understand the system in which they are working, including the social and technical relationships that make up a complex engineering

system [69]. To better facilitate divergent exploration, engineers may benefit from adopting specific strategies that encourage broad perspective-taking. For example, to support intentional divergent exploration, engineering designers might try to frame the problem in a variety of ways to facilitate different takes on who impacts and is impacted by the outcomes [35, 36].

Practitioners named their own personalities and preferences as driving divergent exploration. For individuals, personal qualities such as curiosity, desire to innovate, and team orientation can facilitate the success of stakeholder exploration. Practitioners citing an internal drive to innovate and question norms described prioritizing stakeholder exploration in their projects, sometimes even defying their managers to do so. Treffinger and colleagues [23] described that a key aspect of creativity is listening to one's 'inner voice,' further underlining the role of individual agency on facilitating divergent thinking. These results also contribute to Pacheco and Garcia's [48] call for investigation of personality traits on stakeholder identification. While some engineers may identify as more curious or more driven than others, these are also traits that can be cultivated both internally and in a supportive engineering environment.

5.1 Limitations

This study included twenty interviews with engineering practitioners across various industries. More industry-specific knowledge could emerge by investigating more deeply across engineers from the same industry. However, we found many repeated themes across the practitioners, suggesting saturation of results despite the varied industries. Similarly, each of the engineering projects varied and this study collected only one engineer's perspective on their project. Therefore, we have no external evidence of the projects' 'objective' successes and instead relied on practitioner judgment as to whether a project was successful. External perspectives, such as speaking with other members of the engineers' project teams, could provide a more comprehensive understanding of the success of the process and outcomes of the project.

5.2 Implications for Engineering Practice

Undoubtedly, barriers to and facilitators of divergent exploration of stakeholders interact. Organizations can help by building environments where engineers feel safe to take risks or admit they do not have all the answers. Organizations can also help by building in explicit parts of their processes that have divergent exploration goals. Some of the facilitators of divergent thinking we found appeared to counter the structural barriers revealed in our data: most obviously, while leadership divestment appeared to stop stakeholder exploration, leaders who emphasized the importance of exploration (and provide resources for it) facilitated its practice during projects. Messaging of support for divergent thinking from leadership can promote broad exploration of the people or groups that may impact or be impacted by engineering work.

We suggest that engineering practitioners consider divergent thinking about stakeholders as an approach to support consideration of more diverse perspectives. Divergent thinking has not previously been studied in relation to stakeholder exploration, but it offers unique advantages when seeking to understand and develop strategies to support practitioners. Practitioner experiences suggested that supporting divergent exploration of stakeholders may help practitioners account for more diverse perspectives. The set of stakeholders engineers engage impacts engineering outcomes and there are many examples of inequitable designs resulting from engineers neglecting to consult a diverse set of stakeholders. For example, Buolamwini and Gebru [14] found that darker-skinned women were misclassified up to 34% of the time in commercial facial recognition systems. The datasets informing the facial recognition technology consisted of 79–86% lighter-skinned subjects, suggesting that considering a more diverse group of stakeholders during technology development may support more effective and inclusive design outcomes. Going forward, engineering practice could examine the diversity of stakeholder groups in relation to practitioners' stakeholder exploration strategies.

The environments in which designers engage in projects can be altered to support divergent exploration of stakeholders. For companies, practices can be aligned with exploration by changing reward structures to emphasize collaboration, setting up teams with individuals of diverse identities and areas of expertise, facilitating cross-team consultation, framing projects in a broader system context, and investing in the needed time and resources for divergent exploration. For individuals, leaders can encourage that they follow their curiosity, tolerate feelings of uncertainty about outcomes, and take on exploration despite fear of risk and failure, lack of knowledge, or clarity. The central message is that the added time spent on exploration is not expected to "pay back" in the same way as linear work processes because, by definition, what might be found and how it might help is unknown. Once divergent exploration pays off through experience, divergent thinking's value within the engineering process has made its case.

5.3 Implications for Engineering Education

One suggestion for engineering education is for instructors to make clear and explicit statement of the value of divergent stakeholder exploration in engineering projects with examples of how engineers report its utility in their past projects. Stories from engineers can make the case for the importance of exploration through examples of ways that diverse exploration resulted in "better understanding" and "better problem-solving processes." Relatedly, students could engage in two-part exercises where students first develop a project plan for a presented problem on their own and then learn about an expert's project plan. This approach may encourage students to recognize that exploration is helpful in multiple ways, as evidenced by divergent exploration reports by practicing engineers. Further, explicit instruction with accountability on creating diverse stakeholder maps and exploring multiple problem perspectives can support students in achieving more divergent thinking about who their stakeholders are and how they might be impacted.

The practitioner experiences from this study can inform engineering education, where student engineers may not be familiar with their industry and the ways in which they and organizations can facilitate or inhibit divergent exploration of stakeholders. Our findings about organizational environments suggest that engineers would benefit from understanding impacts these external factors may have on their ability to explore widely. Design educators can reflect themselves on the structure of their educational environments and also help students reflect on aspects of their experiences that are promoting or hindering divergent exploration of stakeholders.

Practicing engineers expressed a lack of known strategies for exploring stakeholders, i.e., identifying a diverse collection of people who impact and are impacted by a problem and its solution, suggesting a gap that further research and development of training pedagogy can fill. To learn how to explore and manage a diverse set of stakeholders, students and early-career engineers need experiences driving divergence in stakeholder engagement.

6. Conclusion

In this study, we investigated engineering practitioner perceptions of barriers and facilitators to divergent thinking about stakeholders through interview data collection with twenty practicing mechanical engineers about their experiences exploring stakeholders. Practitioners named eleven barriers and eight facilitators to their divergent exploration of stakeholders, including ones that related to organizational structures, team dynamics, and personal motivations and cautions. Our findings advance research on engineers' experiences with divergent thinking about stakeholders and contribute to developing ways we can (re)structure design practice and education.

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