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EMPIRICAL RESEARCH

# Exploring Agency in Capstone Design Problem Framing

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**Background:** Because of prior experience solving well-structured problems that have single, correct answers, students often struggle to direct their own design work and may not understand the need to frame ill-structured design problems.

**Purpose:** Framing agency—defined as making decisions that are consequential to framing design problems and learning through this process—sheds light on students' treatment of design problems; by framing, we mean the various actions designers take to understand, define, and bound the problem. Using the construct framing agency, we sought to characterize design team discourse to detect whether students treated design problems as ill- or well-structured and examine the consequences of this treatment.

**Method:** Data were collected through extended participant observation of a capstone design course in a biomedical engineering program at a large research university. Data included audio and video records of design team meetings over the course of framing and solving industry-sponsored problems. For this paper, we analyzed three cases using sociolinguistic content analysis to characterize framing agency and compared the cases to illuminate the nuances of framing agency.

**Results:** All teams faced impasses; one team navigated the impasse by framing the problem, whereas the others treated the problem as given. We identified markers of agency in students' discourse, including tentative language, personal pronouns, and sharing ownership.

**Conclusions:** Framing agency clarifies the kinds of learning experiences students need in order to overcome past experiences dominated by solving archetypical well-structured problems with predetermined solutions.

**Keywords:** design learning; capstone design; agency; opportunity structure

## Introduction and Research Purpose

Numerous studies have investigated teaching and learning engineering design, yet instructors continue to face challenges supporting students both to understand the need to frame problems and to learn how to direct their framing of problems. Design problems differ from other kinds of problems in that, before a solution can be developed, designers first frame the problem (Dorst, 2019). Problem framing can involve many activities, such as identifying stakeholders, assessing their needs, defining requirements, researching existing solutions, and learning about contexts of use. While often depicted as sequential steps, in practice, designers work iteratively (Dorst, 2019), meaning they make decisions not only about what information to collect to structure the problem, but also when to do so.

Students' struggles related to problem framing are anchored in their prior educational experiences, where students almost exclusively encounter well-structured problems (Barlow & Brown, 2020)—that is, problems having a single correct answer and efficient means to reach the answer (Jonassen, 2000). Although problems typically become more complex—meaning, they include more variables and more connections among these (Jonassen, 2000)—as students progress through their educational pathways, the problems they engage typically remain well-structured. For engineering students, most coursework foregrounds technical aspects of problem solving (Russell & Orbey, 1993), reinforcing the notion that problems have correct solutions. These experiences consequently shape students' expectations, resulting in beliefs their careers will entail the use of a linear sequence of steps to deterministically arrive at correct answers (Kirn & Benson, 2018). Thus, when students first face design problems, they are unlikely to recognize that such problems require framing (Christiaans & Almendra, 2010). One way to understand this issue is through the notion of *opportunity structure*—the possible and perceived decision space that is shaped by a range of factors, including prior experiences, norms, cultures, and policies. We use this to consider why—even as design experiences are now being introduced earlier in degree programs—students may not perceive opportunities

to (re)frame design problems. We use the idea of *framing agency*—defined here as making decisions that are consequential to framing design problems and learning—and made visible through design team discourse, to theorize how students encounter and navigate industry-sponsored capstone design experiences. Specifically, we analyze the discourse of three design teams to characterize framing agency. By contrasting teams, we see how students perceived opportunity structures (mis)aligned to problem framing.

## Theoretical Framework

To theorize framing agency, we draw from studies depicting what more and less experienced designers—within engineering and beyond—do to frame design problems. As we consider research on agency broadly, we highlight that design is agentive, meaning designers make many decisions about their framing of the problem and their framing process. In doing so, we contend with "structures," which warrants a brief disambiguation. First, as noted earlier, problems may be ill- to well-*structured* (Jonassen, 2000). Second, the interplay between structure and agency presents a structure-agency dialectic (Giddens, 1984), which pits human decision makers against rather enduring *social structures*. We later introduce *opportunity structures* as an amended and more malleable view of these formations.

### *How do designers frame problems?*

The openness of ill-structured design problems requires designers to frame problems, meaning to explore, expand and structure the problem space (Restrepo & Christiaans, 2004; Schön, 1983), treating the initial design brief—which provides insight about the client, stakeholders, and requirements (Coyne, 2005)—not as the problem, but as a launching-off point to frame the problem. Experienced designers engage in (re)framing deliberately and in ways that differ from less-experienced designers (Reimlinger et al., 2019).

Multiple studies suggest experienced designers explore a broader problem space, relying on varied sources of information to bound the problem (Atman et al., 2008; Morozov et al., 2007). They gather information beyond technical requirements, such as the contexts of use and stakeholder needs (Atman et al., 2008; Morozov et al., 2007). Mohedas et al. (2015) found more successful novice designers used diverse sources of information to develop product requirements and tailor them to the needs of stakeholders. Similarly, compared to first-year undergraduate students, seniors brought more ideas into the problem overall, especially more social and technical ideas (Atman et al., 2008). This does not come from simply investing more time in framing the problem, but in how and what designers do to gather information. Seniors developed better solutions by gathering adequate information, setting up the problem, and making more transitions between steps (Atman et al., 2008). More experienced designers use the information they gather to bound the problem (Atman et al., 2008; Morozov et al., 2007). Thus, experienced designers use their framing agency to explore a broader problem space, considering not just technical, but also social factors and consequences in their design decisions; they use this information to make decisions consequential to the problem frame. In contrast, students commonly emphasize technical over social aspects and draw upon a narrower set of precedents as they make decisions about the problem.

Designers not only gather information to deliberately fill in gaps in their understanding, they also do so to rule out ideas as not feasible and to conjecture about tentative solutions (Atman et al., 2008; Morozov et al., 2007). Experienced designers generate ideas about both the problem and solution (Neeley Jr et al., 2013). Further, they use framing agency to consider and conjecture possible solutions, treating both the problem and solution as tentative and open to revision. Inexperienced designers, on the other hand, leap quickly and firmly to solution (Shum, 1991) and fall subject to fixation (Purcell & Gero, 1996).

Although commonly conceptualized as occurring at the beginning of design processes (Murray et al., 2019; Zahedi & Heaton, 2017), new information and changing context can signal a need to reframe the problem at any point. This makes design an iterative process in which the problem and solution co-evolve (Dorst, 2019; Harfield, 2007). When faced with an untenable or intractable problem, designers reframe (Paton & Dorst, 2011; Schön, 1983). Experienced designers, in contrast to students, more clearly occupy positions of authority that allow them to question the problem frame and direct their process. Thus, experienced designers use their framing agency to direct reframing, making decisions that alter the problem space and their understanding about design requirements and possible solutions. Such acts require significant agency and authority.

Students, lacking such authority, may not recognize their role in directing reframing, but research suggests instruction that emphasizes reframing and empathizing with stakeholders can support students to reframe problems (Kim et al., 2020). Kim and colleagues found that over 90% of students reframed their problem at least once, and in most cases, students reported being prompted to reframe based on stakeholder feedback, which revealed their problems to be insignificant to the stakeholders, or their solution ideas as not usable.

This review suggests that while problem framing may be both challenging and difficult for students to learn to direct, instructional activities show promise for building the diverse skills needed to frame design problems. However, because students do not always recognize the need for problem framing, they may view framing assignments as busywork. Watkins et

al. (2014) warned that students may experience some problem framing tasks *pro forma*, making no connection between the task and their understanding of the problem. For instance, they might be directed to do research on alternative design ideas, but then ignore that research as they consider their own design. This is a gap that framing agency addresses by providing a lens for differentiating such *pro forma* and more agentive moves.

### *Agency in design problem framing*

Framing design problems is agentive in that it requires designers to make many decisions. These decisions are consequential for the problem frame and for how to proceed in solving the problem (Dorst, 2019; Schön, 1983). Yet, the ill-structuredness of design means design decisions are tentative and revocable; as such the kind of agency designers have is also rather liminal (McDonnell, 2018). We argue that this contingent quality calls for a new theorization of agency.

Traditionally, agency has been viewed as a human's capacity to make decisions, set somewhat deterministically within structures that disallow many decisions (Giddens, 1984) and are even "impervious to human agency" (Sewell, 1992, p. 2). Others have described structures as resiliently reproduced (Emirbayer & Mische, 1998). In contrast, we argue that the structures in a design situation may be recast as distributed agency. If we take seriously Schön's (1983) notion of design as a conversation *with* materials, then nonhuman agency imbues the design situation, and further, is distributed across the designers and materials, as well as stakeholders and contexts of use. Increasingly, scholars have treated materials as having agency—that is, talking back to designers interactionally (Tholander et al., 2012). That materials hold agency rather than simply imposing constraints is also evidenced by research showing that experienced designers relax constraints if the problem is over-constrained (Onarheim & Biskjaer, 2017). Rather than being "impervious" structures, treating design requirements as having agency provides insight into how designers might radically reframe a problem (Mohanani et al., 2019).

In participatory and co-design methods, designers commonly share agency with stakeholders (Del Gaudio et al., 2016), but even in less participatory methods, designers invoke stakeholder needs and envision contexts of use as they frame design problems and conjecture solutions. In doing so, they yield their own agency to stakeholders and contexts. Past research on shared agency has emphasized the importance of shared intentions (Bratman, 2013). Amidst the ill-structured design situation, co-designers may (re)negotiate their intentions, but stakeholders external to the design process and context do not have this opportunity. Thus, while we might characterize designers as sharing agency with these external actors, as long as they remain external, they have little opportunity to renegotiate intentions.

In addition to considering ways agency might be distributed or shared, we respond to calls that agency should be treated as contextual (Emirbayer & Mische, 1998), rather than as a generic capacity (Engeström, 2008). Because behaviors and practices are situative, many constructs have been contextualized (Greeno, 1998). For instance, self-efficacy has been studied in a wide variety of contexts, such as in engineering (Mamaril et al., 2016), mathematics (Pajares, 2005), and in teaching with culturally responsive methods (Siwatu, 2007). We argue that agency may become more useful as a construct if we contextualize it.

However, the variety of decisions one makes in any discipline can vary because of the complex range of practices involved. In engineering, for instance, "engineering agency" might include making decisions about which variables to include in an experiment, which stakeholder needs to prioritize when framing, and which material to use following testing. Some decisions can be reached inductively or deductively and checked for accuracy, but others—especially those associated with problem framing—may also be abductive, relying on judgement and preferences, with few clear rules about the quality of the decision (Dorst, 2011), despite being consequential. Thus, rather than contextualizing agency by placing it into a broad discipline encompassing many kinds of reasoning, we chose to contextualize it in light of decision making, to focus on the kinds of decisions students make in framing design problems. To some extent, this means considering both what is changed and in what ways something is changed as a result of the work of framing.

This is similar to the various ways Engeström approached agency, adding modifiers to indicate what agency might accomplish. For instance, Engeström (2008) proposed transformative agency, referencing the capability to use agency to transform organizations through emergent, ongoing collective acts. Similarly, Edwards (2007) proposed relational agency as the capability to offer and seek help based on one's relations with others. These lenses tune attention to the nature of decisions in practice.

Building on this, we offer framing agency as taking opportunities to make decisions that are consequential to how a problem is framed, and therefore, what learning is undertaken to work toward a solution. As such, framing agency is metacognitive work that involves directing and control, while maintaining a tentative stance and sharing agency with co-designers, materials, contexts of use, and stakeholders. These factors differentiate such agency from other forms, such as making decisions to treat design problems as well-structured problems that should be answered accurately and efficiently.

To consider how students might use their agency when facing a design problem, we adapt the notion of opportunity structure. This construct was first proposed to account for youth participation in delinquency and violence (Cloward & Ohlin, 1960), illustrating that society is organized or structured in ways that influence a young person's chances for success. If positive paths to success are inaccessible, young people may take advantage of other opportunity structures, like

gangs. This construct has continued to be used to explain how young people's agency is constrained and to account for their engagement in objectionable activities (Fraser, 1996). More recently, researchers have used this notion to account for participation in activism (Ginwright et al., 2006), social mobility out of poverty (Narayan & Petesch, 2007), and to explain ways adolescents critically construct social identity (Moje, 2000). In these studies, the notion of opportunity structure connects to incentives, access, inclusion, ability to hold those in power accountable, and the capacity to act. As such, opportunity structure shapes agency, but in ways that seem less deterministic than classic views of a structure-agency dialectic (Giddens, 1984). Although rooted in different contexts, opportunity structure draws attention to *perception* of structures, rather than situating structures as impervious. This offers a more hopeful stance on structures and what they might afford, as well as how these affordances might be altered pedagogically. We see opportunity structure as both a means to describe why students might approach design problems from a well-structured problem stance, as well as a means to envision the learning experiences needed to interrupt this. We define opportunity structure as the decision space and set of possibilities one perceives, as shaped by a host of experiences, norms, cultures, and policies, both within the active learning setting and those that came before.

## Methods

We sought to characterize design team discourse in terms of framing agency, and to explore opportunity structure as an interactional tool used by team members to maintain the type of problem space. We address two research questions:

1. What discourse moves and markers are characteristic of framing agency in capstone design teams?
2. How do key markers of framing agency vary as students navigate an impasse in their capstone design projects?

To answer these questions, we drew upon a data corpus collected through long-term participant observation (Atkinson & Hammersley, 1994; DeWalt & DeWalt, 2010), forming theoretical cases (Walton, 1992) generally following procedures outlined for case study (Merriam, 2007). Because designers frame and reframe problems (Paton & Dorst, 2011; Schön, 1983), we sought evidence of framing agency across design process, rather than limiting our investigation to early stages.

## Data Collection, Setting, & Prior Analysis

Data were originally collected in 2005–2008 as part of a suite of studies to understand the impact of new approaches to undergraduate biomedical engineering education (VaNTH ERC, NSF EEC-9876363), which received approval from the University of Texas at Austin IRB (#2006-07-0009) (Svihla, 2010a; Svihla et al., 2012). Students provided consent, including permissions to re-use their data for future studies. The University of New Mexico IRB approved re-analysis (#10915).

As part of a suite of studies, biomedical engineering faculty collaborated with learning scientists to develop challenge-based instruction (Barr et al., 2005; Petrosino et al., 2007). This included, for instance, a biomechanics course in which students were tasked with calculating how much muscle strength is required to hold a specific gymnastic position. The core coursework, therefore, introduced contextualized problems that consistently included complex but well-structured problems. As such, the opportunity structure students became accustomed to was misaligned to problem framing, instead focused primarily on reaching accurate solutions with efficiency.

Yet, three aspects of these challenge-based courses could have prepared students for problem framing. The problems were contextual, meaning students contended with technical problems set within realistic situations, much as engineering design problems are. Students were always scaffolded to consider multiple perspectives on problems, thinking like designers think as they consider varied stakeholder points of view. They were taught to begin problems by identifying key information and defining the system, similar to ways designers approach requirements analysis. However, by pairing these practices with well-structured problems, students may have received the message that the problems engineers encounter are typically solvable without first framing them.

With this in mind, the first two instructors of the senior capstone design two-semester sequence recognized students lacked prior course-based design experience. We documented their course development and annual refinement through field notes and artifacts. They consulted with others about ways to introduce and teach design and considered their own experiences in industry and startups. They reviewed ABET criteria and other design courses to set course objectives. Like many such courses, these included defining and characterizing a design need, solving open-ended problems, defining requirements, including related to regulatory and safety concerns, working professionally with a client and team members, identifying and evaluating resources, developing and evaluating potential solutions, and communicating progress and results in various formats. With staff support, the instructors identified and worked with industry clients to develop diverse projects appropriate to the course in terms of difficulty (i.e., based on the program of studies), ill-structuredness (i.e., the problems were open enough that clients desired them to be framed by the students, or the problems were backburner enough that they did not care if the students framed them in less productive ways), and timing (i.e., clients needed to be fine with the solution delivered at the end of the Spring semester). They developed a course manual with the syllabus,

assignments, deadlines, and grading. Collectively, this presents an opportunity structure that was both aligned and misaligned to problem framing, situating students as responsible for many of the practices professional designers use to frame problems, but not in control of sequencing and directing these practices.

We documented course lectures through field notes. First semester lectures introduced professional skills, such as teamwork and project management, and topics not well integrated into the core coursework, such as market analysis, ethics, and estimation. These lectures were supplemented with activities that emphasized social negotiation and uncertainty. The students estimated how many disposable chopsticks are used annually in Japan to learn about estimation, error, and quantification. They played the Delta Design Game (Bucciarelli, 1999) to highlight design as a social and negotiated process. The played the Beer Game to learn about impacts of delays in supply chains (Sterman, 1992). The instructors introduced design methods and practices, such as how to conduct a needs assessment and use tools like House of Quality, Pugh charts, and TRIZ (Altshuller, 1996; Griffin & Hauser, 1993; Hauser & Clausing, 1988; Pugh & Clausing, 1996). Students were positioned as responsible for using these tools to frame their problems. The second semester included few formal class meetings and typically began with a reminder that design is an iterative process. At the first lecture, in 2008, for instance, the instructor explained "it is my expectation that a lot of you are going to change a lot [...] Some will redefine your problem. [...] This is not a disaster, rather, it is a learning experience." He expressed similar ideas repeatedly throughout his interactions with students.

We also documented weekly one-to-two hour instructor meetings with teaching assistants (TAs). As observers, one member of our team compared this effort to teaching a course, as the instructors often spent time explaining the purpose of specific assignments and what to consider when giving feedback. TAs brought updates about each team's progress, with the group troubleshooting concerns, deciding whether or how to intervene.

Students had many opportunities for formative feedback. Each team met weekly with their TA, who facilitated much of students' work on assignments. Students were graded on the quality of their documentation of their progress in design journals. To situate this as professional practice, the instructor shared his use of his own design journals when he served as an expert witness in a prominent court case. Teams typically met every two weeks with their faculty advisor. The frequency of meetings with clients was highly variable across teams, with some meeting weekly, others meeting only two or three times per semester. The TAs did most of the grading of assignments, using rubrics and supported through weekly meetings with the instructors. Students revised assignments for their project proposals and final design reports, which accounted for most of their final grades, assessed and assigned by the instructors. TAs held practice sessions prior to graded design reviews in which course instructors offered critical feedback and discussed next steps. These in turn helped students prepare for formal design presentations of their project proposal (based on their problem framing) and their final designed solution.

Students worked in teams of four or five, grouped by the instructors, who at the time did not have the benefit of research on team formation that exists today. In an effort to create diverse teams, instructors distributed minoritized students across teams, often isolating these students. Instructors encouraged teams to identify a team leader.

Students completed a mini design challenge spanning two months. Prior analysis contrasted variants of the class to understand how allowing students to select a device to redesign, rather than using a kit-based design challenge, aided them to value the problem framing process (Svihla et al., 2007). Each team was matched to an industry- or university-sponsored project the team had ranked highly. By the end of the Fall semester, students submitted their initial problem proposal, which included problem framing from a largely external lens (patent and internet searches, client-provided data). All case study teams revised this proposal early in the Spring semester as they engaged in more detailed framing activities (needs assessment, requirements analysis). As a result, the impasses students identified became visible only in the Spring semester.

Across three years, we selected six case study teams in which all members provided consent and were open to being followed closely. One researcher documented meetings as a team, with their teaching assistant (TA), with their faculty advisor, and with their client, resulting in approximately 30 hours of audio and video data per team, in addition to field notes and copies of their design work. In the presentation of each case, we introduce the teams. Each team was encouraged to identify a leader. We named the cases using their leader's pseudonym. We assigned pseudonyms that reflected participants' preferred names; for those who used a nickname, we selected a pseudonym that carried a similar level of (in)formality. We asked individuals to specify how they identified themselves in terms of gender, race, and ethnicity.

Prior analysis focused on the varied ways in which teams worked (Svihla et al., 2009) and how teams navigated impasses—situations where team members, having recognized that there was no known and "right" solution, encountered significant challenges in making progress (Svihla, 2009). We considered how these experiences shaped and were shaped by students' efforts to develop their identities, some as biomedical engineers, others as future medical students (Svihla, 2010b). We previously identified and transcribed data leading up to and following such impasses. Given that the teams each worked with different clients, the impasses created a comparative frame. For the current study, since the structure of the teams had been established for the prior study, we selected three relevant cases for reanalysis (Flick, 2018); to support comparisons, we specifically selected cases in which the impasses connected to students' expectations about sensors and the information they ought to provide. We reasoned that this common focus could help us notice variability within a more bounded situation (given the diversity of projects). Two cases did not meet the criterion of focusing on sensors. We omitted one case that

met the criterion, because the client required an additional security review for publications involving direct quotations, and because one member of the team spoke very softly, resulting in many gaps in the transcript. We focused on the emergence and navigation of these impasses, as these were moments where framing agency should be displayed, because designers, when faced with a seemingly intractable problem, typically respond by reframing the problem. This sampling strategy proved suitable, since our goal was to compare specific groups that met certain criteria (Flick, 2018, p. 175).

## Data Analysis

We drew on the tools of discourse analysis (Gee, 2014; Wood & Kroger, 2000) to reanalyze prior transcriptions aimed at verbatim accounts of team talk, including filler words and without corrections. As used here, discourse analysis refers both to the study of the connections between utterances as they unfold in sequence and of language-in-use—meaning, "situation-specific or situated meanings of forms used in specific contexts of use" (Gee, 2014, p. 64). To this end, we began our analysis by adapting the agency toolkit (Konopasky & Sheridan, 2016) and paying particular attention to the social significance of talk among members of each team. Konopasky and Sheridan (2016) interviewed adults about their educational decisions, from dropping out of high school to completing a G.E.D. Grounded in that dataset, they used systemic functional linguistics to characterize the manner and degree of autonomy and intentional causation in interviewee accounts. Systemic functional linguistics attends to the grammar in discourse. Gee defines Discourses as "ways of enacting socially significant identities and associated practices in society through language (social languages) and ways of acting, interacting, valuing, knowing, believing, and using things, tools, and technologies at appropriate times and places" (Gee, 2014, pp. 108–109). From this perspective, recognizing who exhibits agency in this context and to what extent "requires that language integrates smoothly with ways of being and doing" (p. 109). Because we sought to characterize and detect a contextualized form of agency, and one that may be shared with others and objects, we employed a sociolinguistic lens (Gee, 2014) in our approach. We detail these decisions and insights below.

First, Konopasky and Sheridan (2016) defined *manner of autonomy* in terms of how interviewees expressed their expectations and actual outcomes. This aspect was salient for their analysis of interviews, which narrated arguably undesirable histories (e.g., gang membership). We found this aspect to be of limited use, in part because of the interactional nature of our data, which included limited reflection on past decisions, compared to an interview technique. Future work using different post-design interviews should revisit this aspect.

Second, Konopasky and Sheridan (2016) defined *degree of autonomy* in terms of how interviewees represented their agency. They noted various ways interviewees mitigated their agency: placing themselves among many, such as through the generic use of you; using modal verbs that expressed obligation, such as "I had to" rather than "I did"; and using hedges to mitigate action, such as "I just did it" rather than "I did it." In such statements, agency may be offloaded onto external actors or the environment. In their study, interviewees commonly mitigated their agency as they discussed the situations leading to dropping out of high school; for instance, explaining they "had to" get a job. When considering design problem framing, we differentiate between offloading and sharing, between verbs that indicate full, potential or no control. For instance, a designer might share autonomy with or attribute it to another team member, a stakeholder, or a material used in the design. Alternatively, they might offload agency onto the situation or client in the context of a highly constrained problem. In the case of course-based design, they might leave agency with the client, instructor, other experts or the environment. Differentiating between these is critical in characterizing framing agency. And, because we were working with data that included significant future orientations as students discussed what they could do, we particularly attended to how tentatively they expressed their understandings and ideas through verbs and inclusive pronouns showing full control (e.g., "We do that"), potential control (e.g., "We could do that"), and no control (e.g., "We have to do that").

Third, Konopasky and Sheridan (2016) found that their interviewees mitigated their agency using hedges to account for actions that would likely be judged as undesirable, such as getting into a fight, as well as to offload their decisions to drop out onto others or the environment. We chose to treat hedges as separate from degree of autonomy, however, because hedges display tentativeness, endemic to design problem framing. While hedges have commonly been treated as gendered, research suggests context more strongly influences hedge use (Dixon & Foster, 1997), meaning that design contexts should foster increased use of hedges. This does not mean that hedges are independent of agency, as they express uncertainty about that which they modify, be it displaying uncertainty about one's own knowledge, such as "I think" or about the situation "probably happening" (Markkanen & Schröder, 1997). Hedges both express tentativeness and mitigate agency, suggesting framing agency may be characterized as a middle ground, Goldilocks form of agency.

Konopasky and Sheridan differentiated "I" from "we" only when doing so showed a lower degree of autonomy by placing oneself among many. However, in a team-based design context, the use of "I" versus "we" can indicate individual versus shared agency. For instance, a designer might put forward a conjecture about a design solution and show individual agency over it ("I wonder if another sensor could compensate for that?") or offer to share agency with other members ("What if we added another sensor to compensate for that?"). Similarly, Wood and Kroger (2000) characterize first-person pronoun usage as a way of "doing agency" where "the speaker is at least responsible for her or his utterances" (p. 101). In contrast to

the approach of Konopasky and Sheridan, we therefore consistently differentiated between singular and plural first-person pronouns in considering degree of autonomy.

Konopasky and Sheridan (2016) defined *intentional causation* in terms of how interviewees positioned themselves and others as subjects or objects in attributing causality. They characterized this using the subject, verb, and object in a clause. This approach differentiates between, for instance, "I will do it," "I have to do it," "She assigned it to me," and "It is required of me," with the first displaying higher agency, and the others indicating external causation. Konopasky and Sheridan's interviewees tended to show intentional causation, and therefore higher agency, when talking about nonacademic choices, such as working as a waitress. In such instances, they used first-person singular subjects ("I"). Commonly, as they narrated their academic choices, they used first-person plural ("we") or attributed intentions to others, such as the teacher. In the context of problem framing, where we also attend to material and stakeholder agency, we used this approach to differentiate between the subjects of clauses; for instance, students attributed decisions to themselves, their teammates, the client, the context of use, or the materials.

Aligned to Konopasky and Sheridan's treatment of intentional causality and autonomy as *diagnostic tools* in a larger interpretive process that attends to their function in context, we developed a first-pass semi-automated approach. Specifically, we recognized that many of these aspects were straightforward to identify in the transcripts, and therefore developed a template for autocoding (*see supplemental materials).* This approach provided a means to rapidly process larger amounts of data, to evaluate how characteristic an excerpt may be, to evaluate patterns over time and across teams, and to characterize individual speakers. This Excel tool searches each cell for specific words and assigns a score denoting their frequency or omission. As both degree of autonomy and intentional causation depended on these, we developed this tool to streamline the identification of subjects (first-person singular, first-person plural, second-person, third-person) and verbal control (full, potential, no control). In order to increase the accuracy of this approach, we parsed the transcript into clauses. For instance, the utterance, "I don't know if it's gonna work" contains two clauses, which have different subjects and verbs. By breaking this utterance into two clauses, the tool reliably detects the use of a first-person singular subject paired with a full control verb in the former and a third-person subject paired with a potential control verb in the latter. The tool assigns these pairings a unique score, which we connected to forms of agency (**Table 1**). This approach provides a high degree of accuracy in categorizing clauses with "I" and "we" as subjects, as well as identifying potential and no control verbs. By re-sorting the clauses based on these assigned levels, we quickly evaluated the accuracy of all autocoded clauses and corrected those containing second and third-person subjects. This entails removing subject codes when "you" or "it" is an object rather than subject, and adding subject codes when nouns are subjects. We additionally used this tool to identify which clauses contained hedges.

### *Reliability, trustworthiness, & researcher positionality*

*Purposive sampling.* We selected teams deliberately and in close consultation with the faculty and teaching assistants, who each provided lists of teams they thought might be interesting, as well as teams they would rank as high, medium, and low, based on performance on the initial design project. We did this to select teams that maximized heterogeneity, as we sought diversity of experiences.

**Table 1:** Coding for levels of control, from highest agency to lowest agency, as a combination of Konopasky and Sheridan's autonomy and intentional causation. Each row represents a unique score assigned first-pass, but interpretation depends on context.

| Speaker agency | Subject | Verbal control from subject point of view | Example |
|---|---|---|---|
| High | First-person singular | Full control | I will do that |
| High, tentative | First-person singular | Potential control | I could do that |
| High | Second-person singular | Full control | You do that |
| High, tentative | Second-person singular | Potential control | You could do that |
| High | Second-person singular | No control | You must do that |
| Moderate, shared with others | First-person plural | Full control | We do that |
| Moderate, shared with others, tentative | First-person plural | Potential control | We could do that |
| Moderate, objects/others hold tentative locus of control | Third-person | Potential control | It could be |
| Low, others, objects, environment hold locus of control | Third-person | No control | It must be / It is |
| None, external locus of control | First-person singular or plural | No control | I must do that / We must do that |

*Long-term involvement.* The first author attended course sessions and weekly meetings with the instructional team to develop rapport and understanding of the course. They met with each case study team to explain data collection procedures and spent 50–100 hours with each team from November through early May. During this time, they developed rapport with the students. Having worked with the instructional team for several years, the students sought their advice on various aspects of the course and acknowledged them in their final reports. This sustained engagement reduced the chance of spurious inferences (Merriam, 2007).

*Transparency.* When sharing quotes, we do so in sequence and with as much veracity as possible to avoid changing the meaning of participants' talk and foster apparent validity (Peräkylä, 2011). We share our interpretive process, which was subject to iterative refinement, including applying the analytic approach across a range of settings.

*Triangulation.* In our original analysis, we triangulated across data sources and types, for instance comparing students' design journals, emails, meetings as a team and with various mentors, and responses to surveys. We found a high degree of correspondence across these sources. In the current study, we also analyzed students' speaking style, such as their tendency to use hedge words, across a range of interactions.

*Member checking.* Throughout data collection, the first author conducted member checking on early interpretations. Students reviewed results from prior analysis, providing commentary via email. While comments deepened the interpretation, at no point did participants request a modification to the data or illustrations. The analysis reported in the current study was not subject to member checking because of elapsed time. To mitigate this, we have relied heavily on prior data selection and understandings as we have applied a finer grained analytic technique. Our member-checked interpretations in the original work focused on students' perceptions, experiences and navigations of impasses in designing (Svihla, 2009; Svihla et al., 2009). The current study investigates ways agency and opportunity structure played a role in their navigations of impasses, with a stronger emphasis on problem framing.

## Results

In the following, we address the first research question by sharing excerpts from each of the three cases to illustrate displays of agency that are characteristic and untypical of framing agency to explore the opportunity structures the teams developed. We then address the second research question by comparing member talk within and across teams and team talk over time. We present color-coded transcripts as figures to aid interpretation and cross-case comparison. The color-coding aligns to the results of the auto-coding, though our analytical approach reflects traditional qualitative methods.

### *Tom's team*

The first team, led by Tom (a white man) and supported by TA Shanti (a South Asian woman), highlights how members struggle and succeed in framing a design problem. Members Cynthia (a white woman), Addai (a white man), and Greg (a white man), along with Tom were matched to a physical therapist seeking a way to objectively measure limb spasticity.

In late December, Tom, adept at thinking in vectors, recognized what he believed presented a serious issue with accelerometers. Mathematically, he identified a "special case" in which moving exactly opposite to gravity and at the exact same acceleration as gravity should register no movement. In early February, he raised this concern to TA Shanti, and then in detail to his teammates over an hour, shifting from real world examples to mathematical expressions. Members commented on how much they learned from this discussion, both about how the sensor functioned and about the physics involved. While everyone displayed concern as they understood what they labeled as "Tom's special case," Addai offered a solution tentatively, suggesting he did not believe this special case would matter much (**Figure 1**).

Addai put forth his idea in ways that showed he was treating both the problem and his idea as open to revision. He called his idea a "first draft," used hedges, and distanced himself from the idea by using the generic "you," mitigating his agency and responsibility. Addai also located obligation and responsibility with Tom using the possessive pronoun "your" to preserve Tom's "gravitational contribution." Addai's idea called into question whether the measurements by this sensor needed to be highly accurate. Answers to such a question are fundamentally about the problem, even though they are also consequential for the solution.

In response, Tom, who had already considered and ruled this idea out because it failed to solve the mathematical, technical problem, offered encouragement and agreement. This openness to reconsider the idea demonstrates an opportunity structure that supports framing agency. In response, Addai used "we," as an offer to share agency over this tentative idea. Such invitations can lead members to accept, revise, or reject the idea. That members reacted with interest again suggests an opportunity structure supportive of developing framing agency. This reaction supported Addai to continue with his idea (**Figure 2**).

As Addai continued to explore this idea, he owned his uncertainty about it. Such low agency displays invite critique, yet Shanti encouraged the team to try the idea. Her tentativeness (signaled by the omission of "you") left the decision to actually do so with the team. Such moves contribute to an opportunity structure supportive of framing agency; as the TA, she was in a position to assign or expect results of testing by their next meeting. As Addai continued to evaluate his idea, he continued to own his uncertainty ("I think") while distancing himself somewhat, a move that again opened his idea up for

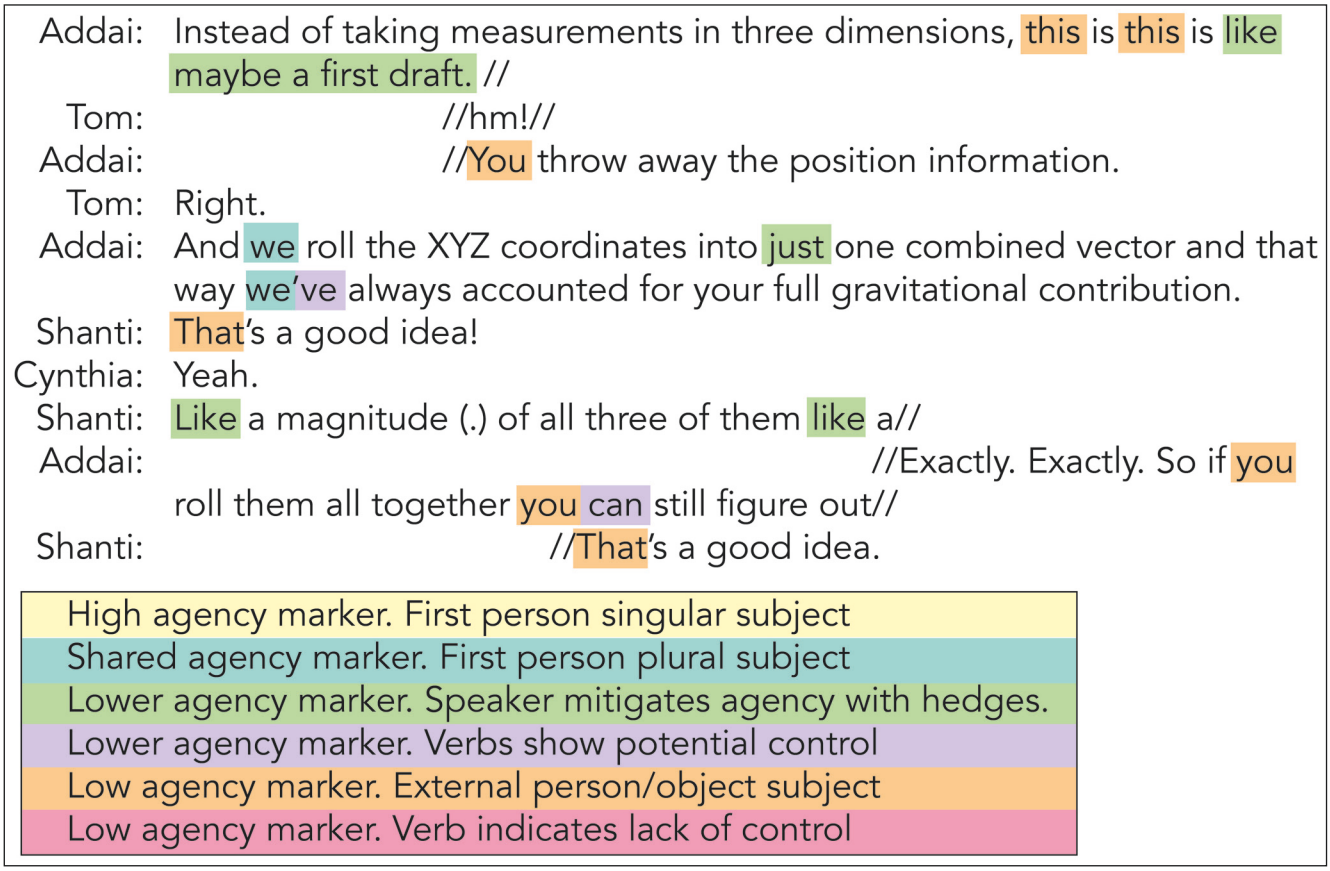


**Figure 1:** Addai tentatively put forth an idea in response to "Tom's special case".

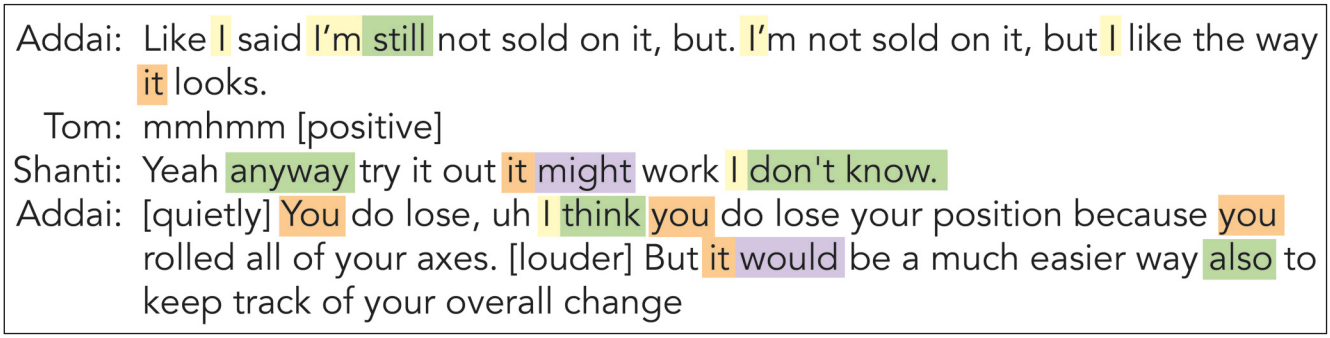


**Figure 2:** Addai, encouraged by Tom, Cynthia, and Shanti, continued to consider his idea. Color-coded as defined in Figure 1.

revision. Encouraged by Shanti's suggestion to "try it out," he displayed more commitment, raising the volume of his talk, as he expressed the value of his idea as a "much easier way."

Over two months, the team considered Addai's tentative solution. Despite Shanti's encouragement to test, to prototype, they resisted until the last possible moment, ultimately finding that Addai's idea, with some refinement, worked well (**Figure 3**).

After the team implemented Addai's idea, he was less tentative, including himself in the collective "we." His explanation displays intentional causation, accounting for the actions members took to arrive at this solution. Shanti's filler responses assured the team she was listening, but she generally remained noncommittal, leaving agency in their hands (e.g., "you're taking the sum of squares"). When Shanti asked "how," she acknowledged the information but prompted and supported Addai to provide a more detailed explanation, while remaining fairly external to the decision-making. Addai appeared to lose some of his confidence, particularly as he began to define a well-established construct ("g"). Tom stepped in as a more capable peer bringing together the loose ends in Addai's explanation. Shanti then shifted to "we," thus including herself in the thought process.

Addai: We calibrated the accelerometer and by doing a square root of sum of squares. He says that it works the way it should.
Shanti: Okay.
Addai: And we subtract out gravity and then we'll stay at zero in a non-moving orientation.
Shanti: So you're taking the sum of squares? Uh:: and then you're subtracting out gravity how?
Addai: Yeah we're doing the square root of sum of squares first what we do is we convert each of those channels by the calibration curves to the units per second squared //
Shanti: //Okay //
Addai: // And then we have, so then we have three axes where there's 100% square root values and then we do sum of squares square rooted
Shanti: Okay
Addai: [quieter] And then we would just subtract 9.8 (.) [quieter still] 'cause 9.8 meters per second per second is the value of g (.)
Tom: It's basically getting a. (.) uh net. (.) acceleration. uh (.) magnitude.
Shanti: [looks concerned] Right.
Tom: and uh (.) which is one contribution of gravity and then mechanical contributions from movement
Shanti: And we don't anticipate any situations like we talked about where the two components would // cancel out
Tom: //Oh yeah like moving around, uh we // only transiently//
Addai: //We don't. We don't anticipate it, we're gonna look at it.

**Figure 3:** Near the end of their project, after finally testing Addai's idea, the team demonstrated shared agency yet remained open to revision. Color-coded as defined in Figure 1.

Across these interactions, Tom and Shanti—both in more powerful roles—fostered and maintained an opportunity structure conducive to design problem framing. This allowed the team to take up a tentative idea—which in turn reframed the problem and shifted it from a purely abstract, technical, mathematical problem to a practical situation, in which an approximation provided sufficient information.

***Steve's team***

The team led by Steve (a white man) and supported by TA Michelle (an Asian woman) highlights how agency can be left with a client and materials. Members Daniela (a Latina), Dillon (an Asian man), and Bob (a white man), along with Steve, were matched to a biomedical technology company that sought to monitor sepsis following surgery. The team identified existing sensors used to measure concentrations of specific chemicals in non-surgical settings. Although it differed from the project as proposed in the brief, the client, rather opportunistically, was pleased to have them conduct animal testing to determine whether the sensors would function in surgical settings. Michelle repeatedly expressed concern that the team was not designing anything and pushed them to redesign some aspect of the sensor. In this way, their impasse was not about how the sensor functioned, but rather, whether the task they were undertaking constituted design work. Their exploration of the problem space stayed externally bounded and technically focused.

In early February, Michelle questioned the students about the worldly value of their project. All the students participated in this discussion, expressing the underlying value of having a means to provide early warnings of shock. This opened a space for Daniela to raise concerns related to the mismatch between their plan and the problem context (**Figure 4**).

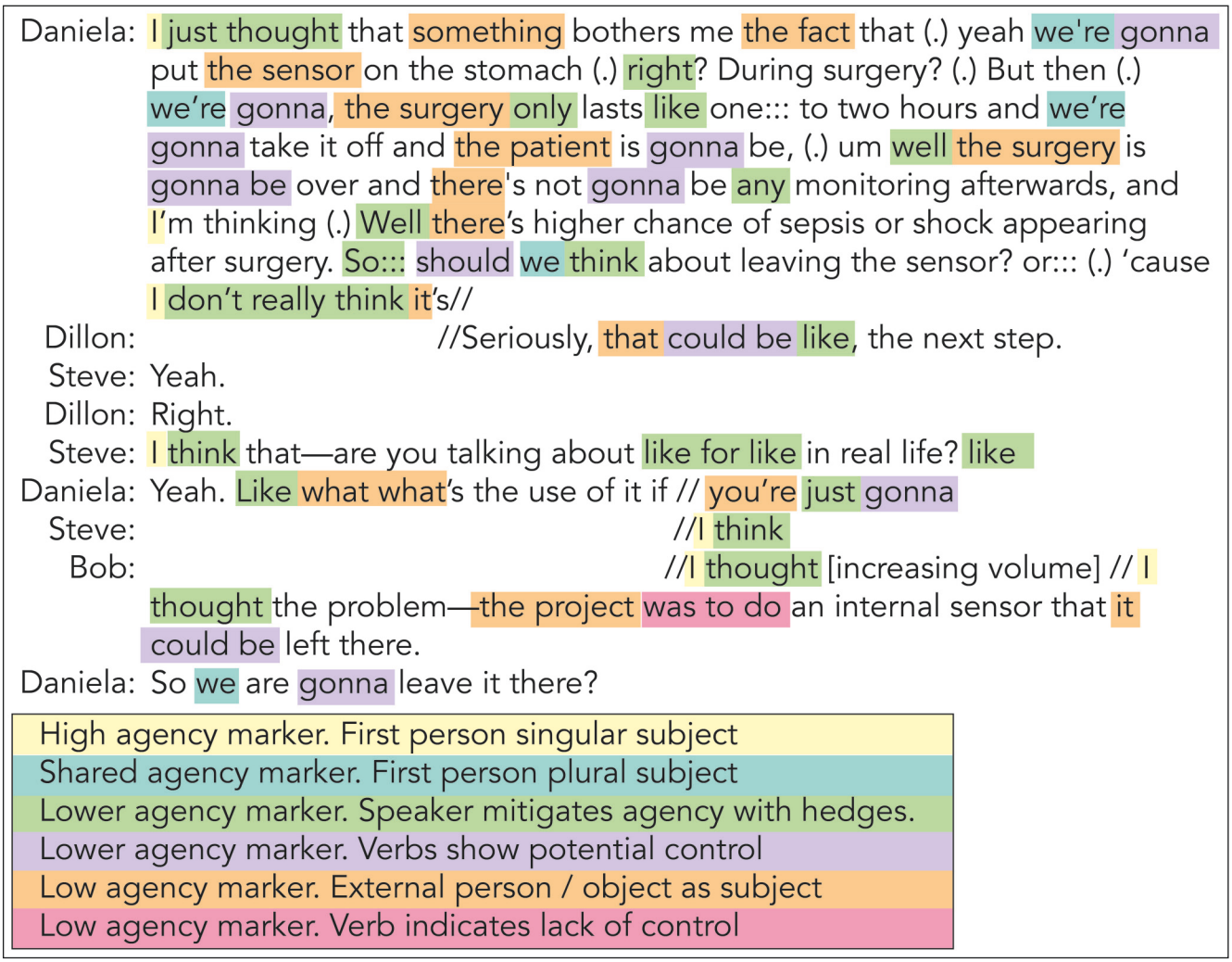


**Figure 4:** Daniela raised concerns about the utility of testing sensors during surgery given that their project was based in providing early warning systems of sepsis following surgery.

Tentatively, Daniela depicted the problem frame resultant from their proposed solution. She owned her concern that this was not addressing the context of use, using the "I" pronoun to locate her thinking ("I thought"; "I don't really think"), and using hedges and verbs that showed uncertainty (e.g., "gonna"), she displayed shared ("we") yet tentative agency over the proposed solution. She also distanced herself from the concerns by placing "the surgery" as the subject of the clause, before hesitantly inviting the team to join her in considering another idea. However, Dillon and Steve responded by dismissing her effort to invoke the context of use as something that "could be like, the next step," and then continued with the use of strong "I" messages that juxtaposed their ideas in relation to Daniela's, who then invoked the pronoun "we," making the idea inclusive and the decision collectively tentative (e.g., "So we are gonna leave it there?"). Here, the use of hedges and verbs showing potential control further reduced the import of Daniela's idea. When Bob then interjected, using passive construction, he situated ownership of the problem as external to their team. Yet, he also aligned to the context of use in mentioning that the sensor could be left in. This opened space for Daniela to invite consideration of the safety of this idea. However, it became clear that the team intended to maintain an opportunity structure that misaligned to design problem framing (**Figure 5**).

Steve established the power position in this discussion at the outset using "I" messages mitigated by the conditional verb "would" to signal some known consequence of the situation (e.g., "I would think that would be") whereas Bob maintained a collective positioning. As Steve quickly shut down efforts to consider the context of use, Bob yielded his position, leaving authority for making use and sense of their planned solution to external actors and situating the team as not responsible for designing. Again, the hedges and verbs showing potential control underlined the unimportance of bringing the context of use into their problem frame. As Steve described the planned solution path, he shared agency with his team, using a few hedges and verbs showing potential control. In this account, he shifted away from invoking a stakeholder to the more technical issue of whether the two available sensors would detect changes in $CO_2$. Notably, across this conversation, TA Michelle

did not interject. This left control of the opportunity structure in the hands of the students, who worked to maintain a well-structured technical problem frame.

The team and TA had several tense exchanges regarding the number of rats they proposed to include in their testing of the sensors (**Figure 6**).

After a brief display of shared ownership over the number of rats, Steve accounted for their number by explaining that external experts had actually made the decision. This is visible in the frequent positioning of external actors as the subjects

Steve: I would think that would be something left up to a surgeon or something to be honest I mean likelikelike our project. I think it's kinda outside the scope of our project our project is//

Bob: //If we left it up to the surgeon and whoever actually designs the sensor.

Steve: Yeah whoever is really doing this.

Bob: 'cause we're not supposed to be designing anything.

Steve: Yeah we're just seeing if we can do it. We just have two types of sensors and we're gonna see if we can do it. We're gonna see if a shock patient whether or not the CO2 levels if it can be measured or changed to a measurable degree enough to be able to detect shock or the on—the //oncoming shock

Bob: //using currently available sensors

**Figure 5:** During the meeting with the TA, the team maintained a focus on a narrow, technical problem. Color-coded as defined in Figures 1 and 4.

Steve: You wanted to know where we got those numbers for the rats and I think that you took that as like defensiveness but in reality, like, the USDA- they say if there's no previous data, that's acceptable for a professional to recommend a number.

Michelle: Well, 'cause I talked to somebody else and she, she gave me a reason why they used eight, so and I'm still kind of waiting for you guys to figure that out.

Steve: I mean, I was shown literally verbatim, word for word, by the guy who's in charge of [the group running animal labs] who is the liaison between [the lab] and researchers and he showed me if there is no statistical data available then they report recommendations without say, decades and decades of animal research experience.

R: Can you, can you get them to explain why they would use that number?

Steve: Yeah, and I mean, I totally agree with that with, like why eight? Or why?

R: Why the expert would say eight?

Steve: Because I think it allows for enough variation in there, I think it allows for variation if you're gonna have, it's a relatively arbitrary number but it's, I mean if you had four, I mean, that's not gonna be enough if one of them is way off the charts in another direction, then that's gonna statistically mess up, and so eight I think falls into some sort of acceptable range. I mean, I don't have a wonderful explanation for that.

Michelle: No, that's exactly what I was looking for!

**Figure 6:** After TA Michelle repeatedly asked the team to justify the number of rats in their study, the researcher (R) reframed the question. Color-coded as defined in Figures 1 and 4.

Steve: However, there is no conclusive results from these. They don't all follow the exact same - the exact same patterns, but rather they are similar to one another. […] We left the sensor in and just recorded the values over an arbitrary amount of time just to have these data and we feel these are very important data because each one of these shows a linear increase in pCO2 following death as one would expect. It's - this indicates that the sensor was functioning correctly.

**Figure 7:** At their final presentation, Steve summarized the results of their testing and modeling of data. Color-coded as defined in Figures 1 and 4.

of clauses, the lower use of hedge words, and some passive construction. Seeing the lack of progress, the researcher shifted from observer to participant and reframed the question, which Steve initially missed. His explanation displayed some knowledge as well as uncertainty. As Michelle confirmed that this was indeed the information she desired, she also maintained the opportunity structure as one that emphasized accuracy. Shortly after this, Steve expressed frustration, "It's just my biggest, my biggest frustration with this is just, like this, like this is the project, like *this is the project we were given,*" again suggesting the team viewed their role as solving, but not framing the problem. In this statement, Steve delegates causation to the client and instructor and suggests his team lacked autonomy to reframe. One could view this exchange as a conflict between messages from the course instructors and the client. Yet, the client never demanded any particular approach, in line with the ill-structured and backburner nature of this project.

Near the end of the project, it was evident that they continued to allow others and materials to frame the problem (**Figure 7**).

Steve's account of the results maintains a focus on technical performance and accuracy, which highlights his authoritative position. He maintains that results are inconclusive because they failed to show the "exact same patterns." Further, his explanation of leaving the sensor over an "arbitrary" time, his abundant positioning of others and materials as subjects, and his summary that the sensor was "functioning correctly," all suggest an opportunity structure misaligned to design problem framing.

Across the interactions, TA Michelle challenged the team to ensure their project included design, offering ideas related to redesigning the sensor to be biocompatible or designing a model. While they did statistically model their results, showing the sensors' functions, and their client was certainly pleased, the team's work stayed technical and well-structured. Although Daniela attempted to critique their work by invoking the context of use and displayed framing agency, her efforts had little impact on the problem frame.

### Shawn's team

The team led by Shawn (a white man) and supported by TA Sanjay (a South Asian man) illustrates how a well-structured but complex sub-problem can keep a team focused on right answers rather than on framing design problems. Members Menaka (a South Asian woman), Colin (a white man), and Todd (a white man), along with Shawn were matched with a university project to develop a way for a specific device that measured material properties to interface with existing analysis software, along with a set of biomedically-relevant exemplars that could be used instructionally.

Early in their project, TA Sanjay encouraged the students to work concurrently on subproblems, which included hardware development, software development, and instructional materials on how to use not only the existing device and software, but especially on how to interface these. In part because of the clear divisibility of their project, the students tended to work in silos, with Menaka and Todd developing instructional materials, and Shawn and Colin developing software and hardware respectively. As such, we observed few instances where Menaka and Todd participated in considerations of the problem frame; rather, they typically took direction from Shawn and Colin. In an early February meeting with the TA, Shawn reported his progress (**Figure 8**).

In this excerpt, Shawn positions himself as beholden to the tasks rather than as an agent, and in doing so, delegates causation to the tasks rather than showing intentional causation. He uses the adverb "still" with verb phrases like "have to go" and "have to do" to signal the team's lack of progress, to emphasize the burden, and to indicate his own lack of control in moving things forward. This reflected his knowledge of the impasse—that for some unknown reason, interfacing the hardware and software was not straightforward. He then shared his agency with his team, or perhaps with Colin, regarding software-related subtasks, before bringing up his hope that others would contribute to some of the more straightforward software subtasks, with which Colin later agreed to help. In positioning himself as not controlling these tasks, but instead, as "still"

having to do them, Shawn mitigated his agency as a designer and as the team leader. By suggesting they simply needed to complete basic tasks to reach the correct solution, the opportunity structure is misaligned to design problem framing.

A few weeks later, Shawn and Colin reported continued difficulties and plans to seek external help at a meeting with their TA (**Figure 9**).

Throughout this excerpt, the team treated the problem as having right answers. Through a series of *could*s and *would*s, Colin and Shawn pointed to tentative possibilities and consequences in discussing the problem. Colin, for example, placed agency on the external experts and designed artifacts, like the "blank VI," which referenced a virtual instrument that is a basic unit of the software. From Colin's point of view, having this as a template should make their work straightforward. The uncertainty he expressed, rather than being focused on whether it would be useful, centered on whether the external

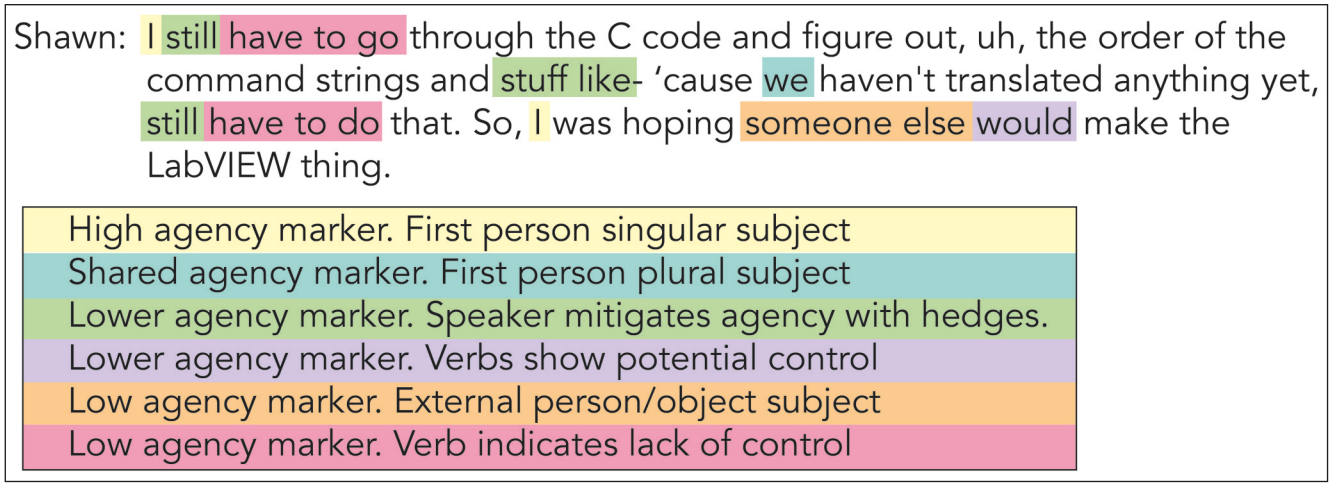


**Figure 8:** Shawn reported his progress.

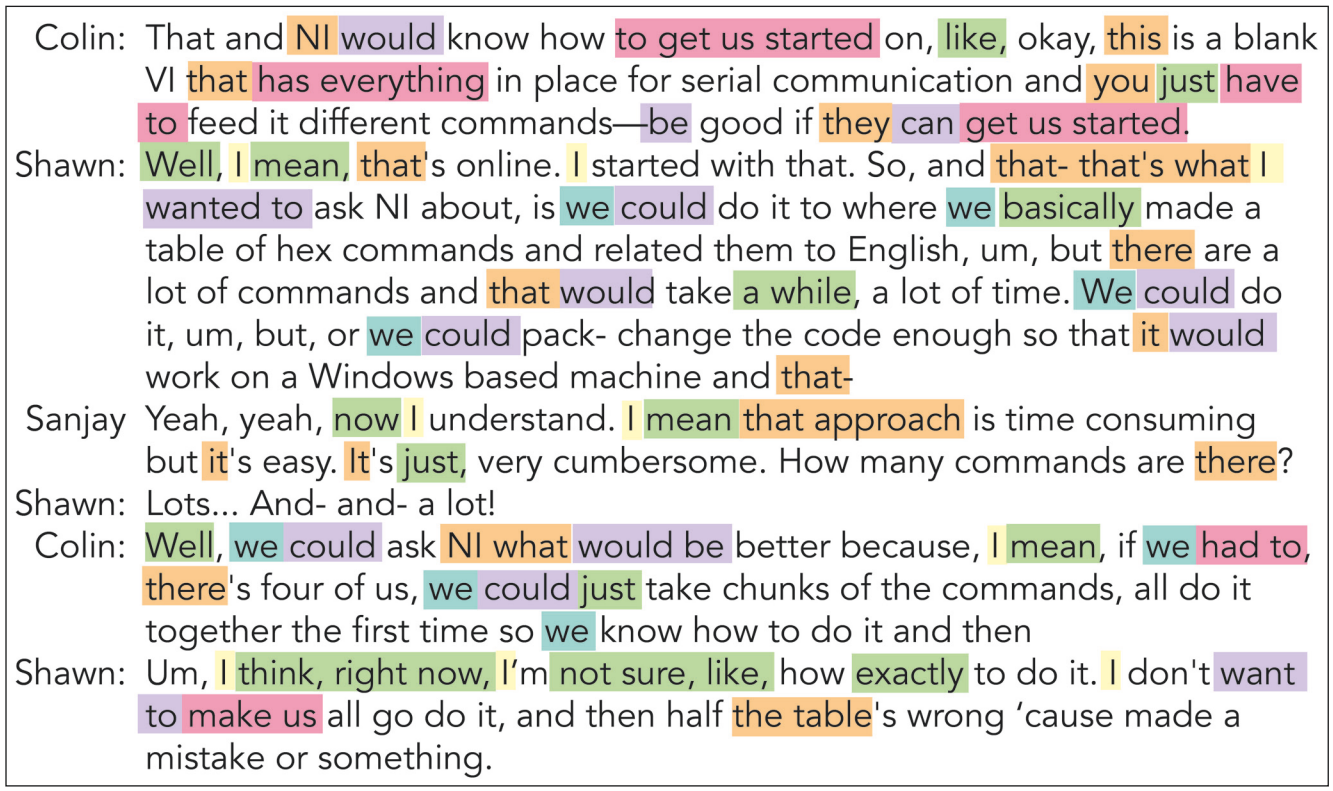


**Figure 9:** Shawn and Colin, facing difficulties, considered external help during a meeting with their TA. Color-coded as defined in Figures 1, 4, and 8.

software company would make it available. In response, Shawn concisely explained that the software company allowed it to be downloaded from their website. He then shifted to a possible solution to the impasse, explaining, essentially, that they could write a new program, rather than figuring out why the hardware was not interfacing with the existing software. In his explanation of this solution, Shawn shared agency with his team and treated this solution as tentative. In this case, his tentativeness seemed to be about the undesirability of the effort associated with this solution. In response to Sanjay's acknowledgement of this, Colin built on Shawn's suggestion of seeking advice from the external software company on whether to pursue this solution. In doing so, he distanced himself and his team from the decision, again suggesting both a lack of autonomy and delegating causation. Shawn's initial hedgy response, paired with reluctance to lead them down a wrong path, suggests uncertainty, perhaps about whether the solution he proposed would really work, or whether it would be better to invest more effort to understand why the hardware was not interfacing with the software. Immediately following, the team focused on ways to reach out to the external software company. As Shawn depicted the proposed solution, he illustrated an opportunity structure of cumbersome but well-structured work, with external experts (with)holding answers.

One month later, again at a meeting with their TA, Shawn and Colin reported on continued difficulties despite interactions with external help (**Figure 10**).

In reporting on his conversation with someone from the external software company, Shawn depicted a conversation with an opportunity structure aligned to problem framing. Rather than solving their problem, this external agent made various suggestions. As Shawn makes this report, he shared agency with his team, used hedges to display his uncertainty about the

Shawn: The problem that he thinks we're having now is some disparity between the high level C code and what's actually getting hooked through the serial port, so he suggested that we, um, uh, try to send a message that we know. […] Basically what we tried to do before. […] He also suggested that we might wanna look into- or that we should look at- try and find the actual Palm library and figure out what it does. […] I'm not sure how much I agree, I mean, granted he is the superior authority here but it-it seemed to me that with the library documentation that pretty much already says what the code does and when you set parameters for serial things you should get reproducible results of… I don't know how much we could really gain by looking for the serial API but at the same time there's a road block so.

Colin: He didn't give any pointers for LabVIEW.

Shawn: He didn't know about voltages like what is high and low what should be, what the serial port does. Said he thinks the serial port just goes from zero to three anyway so it should match up, but then I don't know what our problem is so- and then I took a break for a week and didn't think about it. That's pretty much…

Sanjay: Okay. Soooo.

Shawn: It wasn't as helpful as I had hoped.

Sanjay: So, it kind of puts you back where you were before the meeting.

Shawn: Yeah.

Sanjay: I'm not sure you gathered any more information from the meeting.

Shawn: Yeah. I mean it seemed so at the time and then on the drive home, I was, you know, it happens, come up with questions after it's over. Just didn't think about them then. Basically the guys I talked to didn't know low level stuff. They don't know about writing drivers or anything like that so if, if it turns out that that's what we need to do, we need to get transferred again.

**Figure 10:** Shawn and Colin reported on their meeting with external experts. Color-coded as defined in Figures 1, 4, and 8.

Shawn: This just converts them to the appropriate range. […] That's all it took really, uh and once we had that it turned out that everything we had was right, it was just the wrong voltages.

**Figure 11:** Shawn explained solving the problem. Color-coded as defined in Figures 1, 4, and 8.

suggestions, and ultimately questioned the expertise of the person with whom he had met, perhaps because the interaction did not result in a solution. Sanjay reinforced this view, and in turn, also sustained an opportunity structure misaligned to problem framing. In response, Shawn positioned himself as not having agency to solve the problem, and instead, needing to find another external actor who could do so.

Two weeks later, Shawn reported, "turns out, we were looking at the voltages wrong." He did not elaborate on how he uncovered this, but instead focused on their planned next steps. TA Sanjay did not inquire, but instead offered reassurance that they were "making really good progress." Two weeks later, Shawn summarized their success (**Figure 11**).

Shawn's account of success reflected a diminished technical problem space, solved simply with purchase of a device to convert voltages, as the adverbs "just" and "really" indicate. In using the personal pronoun "we," Shawn shared ownership over the work with his team, but also left much of the agency to the technical objects.

Across these interactions, the team and TA maintained an opportunity structure misaligned to design problem framing by seeking right answers to technical problems. The ease with which the problem was broken into subtasks contributed to this, as the problems Shawn and Colin addressed were indeed well-structured (albeit complex) and lacked context.

## Cross case analysis and discussion

We found that TAs and team leaders had critical roles in shaping opportunity structures (mis)aligned to problem framing and influenced how students distributed their agency, which sustained these structures. Hedges and offers to share agency invited reframing, but these invitations were not always accepted. Silence was also a mediating factor that both supported and disrupted framing.

We next purposively compare and contrast these design teams according to the markers of framing agency they displayed and the opportunity structures they fostered as the teams navigated impasses. Specifically, we compare the use of hedges, particular subjects (first-person singular, plural, second-person, third-person) and adverbs and verbs showing full, potential, and no control across speakers within teams and across teams over time. For this, we rely on both the corrected autocoded analysis and our discourse analysis.

### *Opportunity structures are shaped by TAs and leaders*

Because many of their past educational experiences focus on solving well-structured problems with accuracy and efficiency (Barlow & Brown, 2020), students commonly expect that all problems share these characteristics (Kim & Benson, 2018) and may not recognize the need to frame design problems (Christiaans & Almendra, 2010). We introduced the idea of opportunity structure to bring attention to the opportunities students perceived, structured by and for them, and to treat design problems as needing to be framed or simply solved. From our case analyses, it became clear TAs and team leaders played a role in shaping opportunity structures in ways (mis)aligned to design problem framing. In comparing corrected, autocoded data across cases, we noted the TAs never paired first-person subjects with verbs showing no control (**Figure 12**). This suggests they all showed ownership over their roles as TAs and underscores the notion that power is inherent to agency (Wood & Kroger, 2000). The TAs used second person more frequently than team members, which reflected their position. In contrast to the TAs, team leaders (Tom, Steve, Shawn) all paired first-person subjects with verbs showing no control (**Figure 12**). Steve and Shawn directed their members, using the pronoun "you," which signaled their status in relation to the members. Yet these similarities do little to illustrate how differently they scaffolded their teams and shaped opportunity structure. For this, we turn back to discourse analysis.

When facing an impasse associated with their sensor's function—much as the other teams faced—Shanti and Tom encouraged Addai to expand and consider his idea, even though Tom had already evaluated it as not solving the abstract technical problem as he envisioned it. They accomplished this with *supportive filler*, by showing interest and sustaining space for the team to consider and work on the idea. Even though she wanted the team to prototype, Shanti left the decision of when to do so in their hands. Thus, these individuals who possessed greater authority exercised patience, in turn showing they valued the contributions members might make. In mitigating the impacts of the power associated with their roles, they shaped an opportunity structure aligned to framing agency.

In contrast, the other teams' leaders and TAs shaped opportunity structure misaligned to framing agency, but in different ways. Michelle, in contrast to Shanti, pressed her team to bring design into their project. As such, she was often at odds

with Steve, and in a critical moment, when Daniela attempted to reframe the problem, Michelle remained silent. Steve then affirmed an opportunity structure misaligned to problem framing, with a critical disconnection from the context of use. Quite differently, Sanjay and Shawn appeared to be in agreement in many instances, and Sanjay offered guidance in a manner similar to Shanti, but different in content. While he did not require his students to take a divide-and-conquer approach, his suggestion was readily taken up and reduced the broader problem into addressable subtasks. This helped shape an opportunity structure misaligned to problem framing by both reducing the number of team members able to contribute and centering the decontextualized and technical aspects. We argue that their problem, in particular, lent itself to this approach, and because it was only sparsely contextualized to begin with, that it was not an ideal project for learning to design. Had the subproblems been entangled consequentially with context, the students might have found more reasons to negotiate their ideas.

### *Distributing agency beyond the team sustains opportunity structures*

We argue that designers commonly distribute their agency as they converse with materials and envision stakeholders' needs and contexts of use (Schön, 1983). While experienced designers do so amidst opportunity structures aligned to problem framing, students may take cues from and reproduce misaligned structures in the process.

In the case of Steve's team, members attributed decisions to "experts," the client, and the problem they were "given." They seldom referenced the context of use, though this was clearly indicated in the design brief their client provided. Likewise, in Shawn's team, the technically-focused subteam attributed and clearly sought out expert decisions. In contrast, members questioned Tom's concern about the accelerometer, with Cynthia sometimes invoking the context by moving her hand into the conversational space and displaying a tremoring motion—as if becoming the patient—to remind the team of the kinds of movement they were aiming to measure. We see all of these references to outside actors or contexts not as the clients imposing themselves or exercising their own framing agency, but rather, as the students invoking them to borrow their power, in turn warranting decisions and shaping opportunity structures in ways that (mis)align to design problem framing.

Using the corrected, autocoded analysis, we see that all teams placed others and objects as the subject, using third person more than first person singular or plural pronouns (**Figure 12**). That the objects were commonly the sensors aligns to research showing that less experienced engineering designers commonly foreground technical over social aspects of design problems, leading to narrower problem frames (Atman et al., 2008). Further, how team members used talk to mitigate this action is especially significant here. For instance, across the three teams, we observed that this attention to the technical narrowed the problem to having a presumed right answer, but this in turn created impasses. For Steve's team, the impasse centered on the concern that simply testing commercially-available sensors in an environment for which they were not designed was insufficient for a design project. When reporting on their successful data collection, we see use of third person ("it's simply monitoring on the stomach") that foregrounded the technical success.

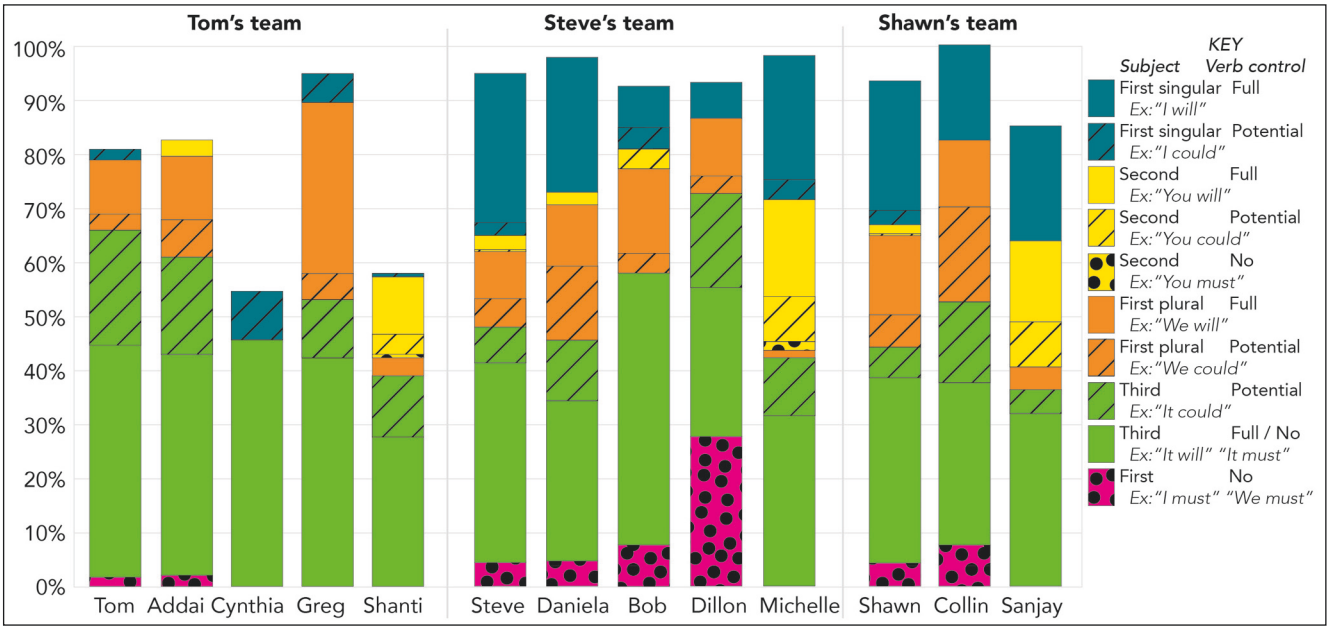


**Figure 12:** Team member discourse, aggregate over time, characterized in terms of framing agency. Clauses coded as containing verbs showing potential control are denoted with diagonal lines and showing no control with dots. Some utterances were not codable using this scheme, resulting in totals less than 100%.

For Shawn's team, the technical problem was vexing because it appeared well-structured and solvable, yet the problem stubbornly resisted being solved, as if the materials themselves were reluctant to work with the students. When Shawn reported their solution, the team still interpreted their role as solving a well-structured problem, using first-person no-control clauses to describe their solution (e.g., "We have everything the way it's supposed to be"). In both cases, these teams responded to difficulties by seeking answers from external actors, with Steve treating the information gained as beyond question, and Shawn dismayed that the suggestions did not solve his problem.

Steve's and Shawn's teams seldom used verbs showing potential control in tandem with third-person subjects. These two teams commonly situated technical objects and external experts as subjects in full control, and in both cases, members sought external information to arrive at correct answers to technical issues. In one excerpt from Shawn's team where the external expert was positioned as displaying potential control, Shawn mitigated the impact this had because it did not solve their technical problem (**Figure 10**).

In contrast, for Tom's team, the impasse stemmed from his precise understanding of abstract physics, unanchored to the reality of use, and the intractable quality of this impasse is visible in first-person, no-control clauses (e.g., "And so what we need to do is," **Figure 14**, Feb. 4). Addai's idea invited the others to treat "Tom's special case" as uncertain, to entertain the possibility that though the sensor might not be accurate under all uses, it might suffice. Tom helped the members understand the impasse associated with the accelerometer by asking them to consider various hypothetical situations, reflected in a high percentage of third-person potential clauses (e.g., "the hand is gonna have two orientations to start," **Figure 13**, Feb. 4th). Overall, Tom's team commonly used verbs showing potential control in tandem with third-person subjects, be they materials or humans (**Figure 13**). Thus, in distributing their agency, members did so in ways that reproduced and reinforced the already shaped opportunity structure, with Tom's team treating materials, stakeholders, and contexts of use as malleable and uncertain, and the other teams treating experts as providing accurate answers about predictable technical materials.

### *Hedges can invite reframing*

Research has characterized women as using hedges more frequently than men (Magnifico & Defrancq, 2017; Mirzapour, 2016), yet in our teams, we found no support for this. Our findings align with research suggesting context more strongly influences use of hedges (Dixon & Foster, 1997). However, because all teams and all speakers used hedges (**Figure 14**), use of hedges sheds little light on framing agency (**Figure 14**) without also evaluating *what* interlocutors express uncertainty about. For instance, when Shawn used hedges and verbs indicating potential control to describe a cumbersome solution (**Figure 9**), his use may have paralleled Konopasky and Sheridan's (2016) interviewees who used hedges when describing undesirable histories. Likewise, when Steve used hedges in response to Daniela's efforts to invoke context of use to critique the planned sensor testing, the hedges served not to invite reframing, but to mitigate Daniela's critique (**Figure 4** and **5**). In contrast, Addai's hedges, which were linked both to his own uncertainty and to the materials involved in the design, invited

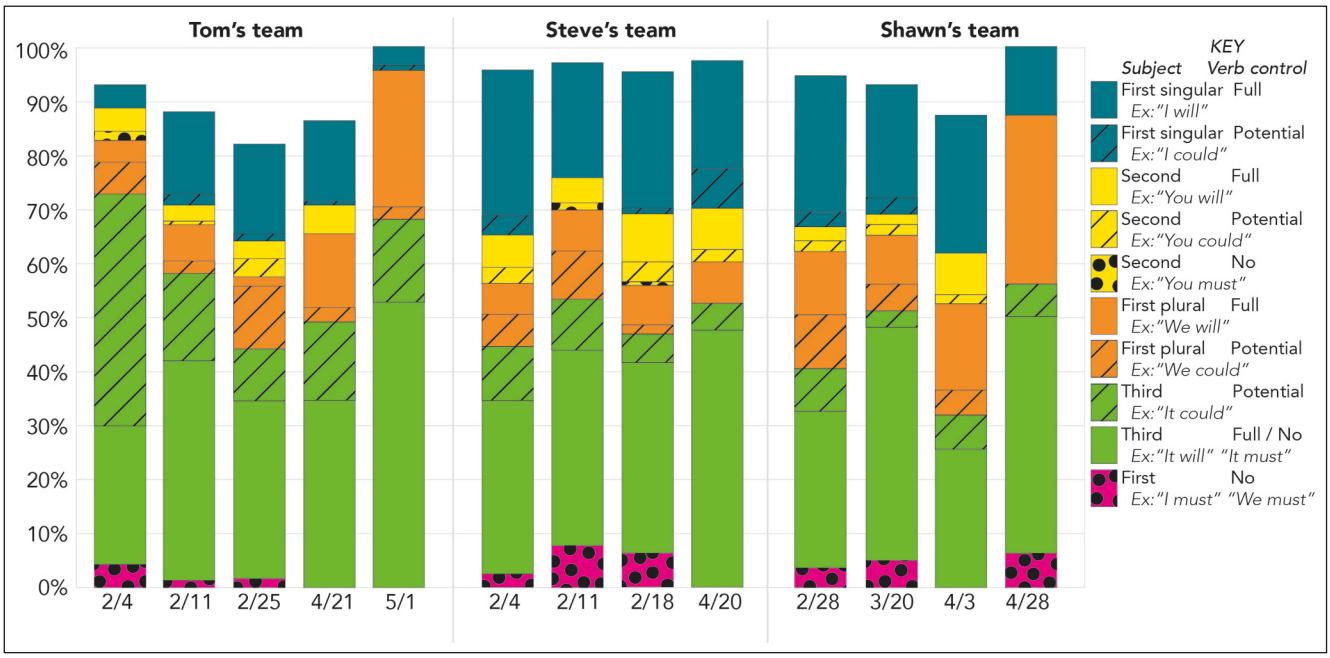


**Figure 13:** Team discourse over time, aggregated across members include TAs. Note that a majority of second-person clauses originated from TAs, as seen in Figure 13.

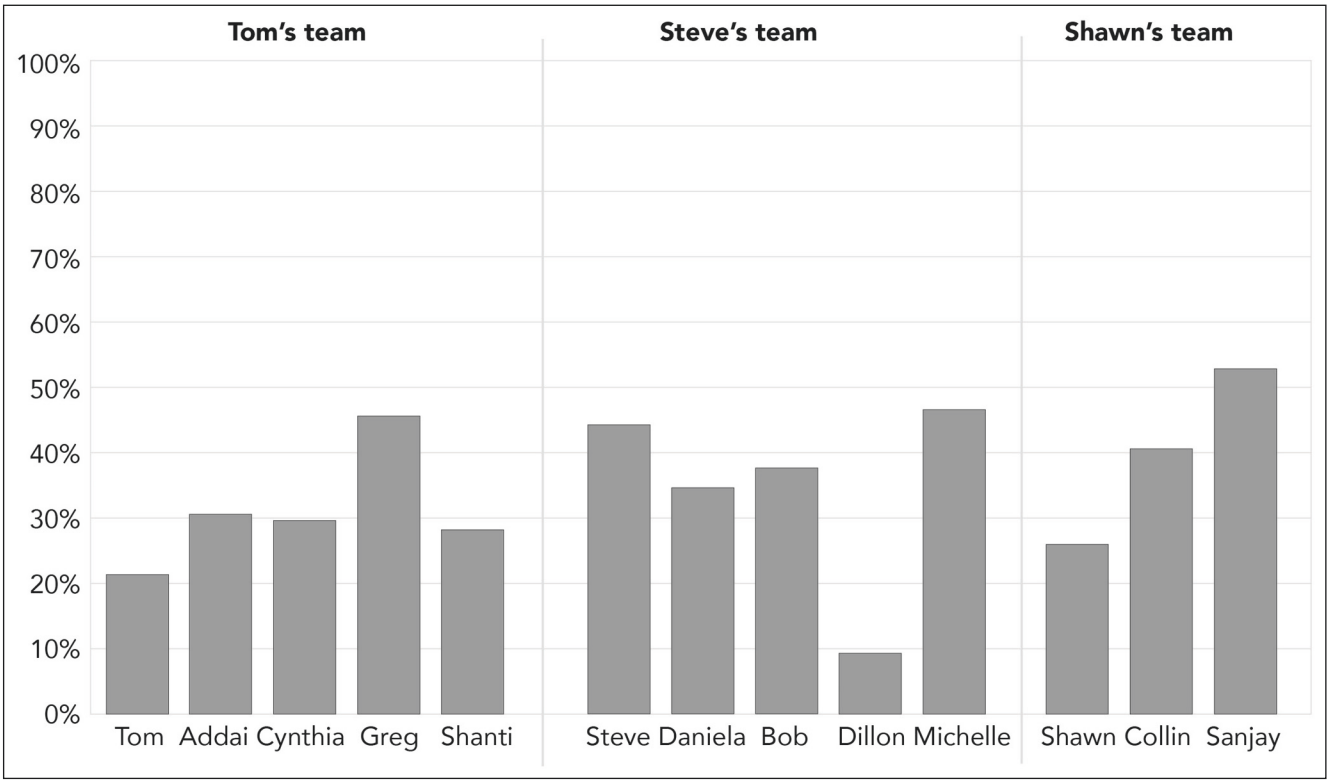


**Figure 14:** Percent of clauses containing a hedge, within teams and across members, including teaching assistants (Shanti, Michelle, Sanjay). Speakers displayed variable tendency to use hedges.

others to join him in reframing, which was supported by those with more authority. In this way, when those in more powerful positions (and deemed experts) recognize hedges not as expressions of low confidence, but as tentativeness appropriate to problem framing, they can sustain an opportunity structure aligned to problem framing.

### *Offers to share agency invite reframing*

Also of interest in understanding framing agency is the degree to which use of "we" is indicative of shared agency. Scholars emphasize that in addition to marking agency as shared through the use of "we," shared agency stems from shared intentions (Bratman, 2013; Peele-Eady & Moje, 2020). Yet the precursors of shared intentions may commonly begin as individual ideas to which others are invited. We consider the ways "we" suggests an invitation, a coercion, or evidences shared intent. Certainly, late in their projects, especially in accounting for resolved impasses, shared agency is evident. For instance, on Tom's team (**Figure 13**), having tested and developed Addai's idea, we no longer find first-person no-control clauses (novice moves). Instead, we see a stronger display of shared, first-person plural, full-control statements ("we convert each of those by the calibration curves") paired with third-person clauses describing how their solution functioned ("so the accelerometer is just in a position, like it is now").

Shawn used "we" to share a burdensome possible solution with his team (**Figure 9**), to situate next steps as jointly required (**Figure 10**), and ultimately to share the resolution of the problem (**Figure 11**). These do not strongly suggest shared intent, but they do appear to be offerings situated on a novice-expert continuum, with the second example clearly misaligned to a framing opportunity structure.

On Steve's team, each member spoke more for themselves ("I mean"; "I think") than as a collective ("we're making progress"). They responded to Michelle's suggestions to at least design a model with first-person plural, no-control clauses ("we're not supposed to be designing anything," **Figure 5**). When Daniella troubled the plan, she used "we" to jointly offer and question shared intent, inviting members to reframe, an invitation declined (**Figure 4**). By the end of their project, while we no longer see no-control displays, we also see diminished shared agency (**Figure 13**).

### *Implications and Limitations*

By comparing and contrasting these cases, we gained insight into the kinds of experiences that help learners use their agency to frame design problems. Our findings suggest a range of scaffolding strategies instructors could implement in design teaching to affirm the importance of having multiple opportunities to learn *how* to design. In the cases presented

herein, the instructors did much to provide an opportunity structure that invited problem framing—developing ill-structured industry-sponsored projects, supporting students to use design methods that professionals use to frame problems, and explicitly situating design problems as needing iterative reframing. As such, we see the shift from solving well-structured problems to framing ill-structured problems to be particularly challenging, even for students who seem to embrace it, like Tom's entire team and Daniella, on Steve's team. This shift involves leaving more control with students, but also being ready to coach them on what this looks like in practice. For instance, instructors could share cases of design projects that highlight iteration and reframing, drawing attention to how designers revisit steps in a design model; this could interrupt perceptions students may gain from models that depict design as a sequential set of steps.

Instructional teams can prepare themselves to mitigate the effects of their influence on students' agency, yet be ready to intervene when students steer towards opportunity structures that misalign to framing. This means attending to design talk and recognizing that hedges that mitigate the speaker's certainty and the certainty of the materials, using the pronoun "we" to invite framing, and using adverbs and verbs that express potential control and knowledge authority are productive. Instructors could review the excerpts in this paper with TAs to discuss how they might have responded in each situation. And although future work is needed, instructors could share the simple color-coded scheme (**Figure 1**) and an excerpt with students to raise their awareness of how their team discourse might be aligned to problem framing.

As instructors recruit clients or develop projects for teaching, emphasizing contexts of use may be beneficial for fostering framing agency. By entangling technical aspects with contexts of use and encouraging students to not rule out ideas on purely technical grounds, instructors could help students engage with the problem in broader ways.

While this study offers insight into a critical aspect of supporting students to develop as designers, it also comes with limitations that suggest a new agenda of research. First, we characterized the design project that Shawn's team worked on as lacking sufficient context and being too straightforward to break into subtasks; this stripped away opportunities for negotiation. We advise instructors to review prospective clients and design briefs with this in mind, considering ways to entangle the social with the technical, and by either avoiding projects that too easily break into separable parts, or by developing check-in conversations that encourage students to make decisions together. However, additional work is needed that investigates the instructional value of various characteristics of design problems for supporting framing agency. Similarly, we need research that links specific instructional moves to supporting framing agency, and in particular, interrupting opportunity structure misaligned to problem framing.

To focus our study on the close interactional and discursive moves in framing agency, we glossed much about the instructional interactions in the capstone course, focusing instead on pedagogical moves by TAs and team members specifically. We can speak, however, to some of the broader instructional approaches that might have shaped the course context, but as these did not vary from cohort to cohort, these insights should be treated as exploratory. The course instructors positioned students as responsible for framing design problems in several ways. Because each team was matched to a client and made responsible for delivering an initial and revised proposal and a designed solution, students were allowed to occupy roles as designers. The draft and final versions of assignments paced students through many of the practices designers use to frame problems. However, presenting design tasks as assignments might have suggested they were no different from any other course assignment for which the correct answer earns full credit. Likewise, instructor-set deadlines afforded students fewer opportunities to learn to direct their own processes.

Although researchers have treated problem framing as a front-end process (Murray et al., 2019; Zahedi & Heaton, 2017), the knowledge that new information can provoke reframing (Dorst, 2019; Harfield, 2007) led us to prioritize looking across months of design work for evidence of framing agency. To aid us in navigating a large corpus, we developed an automated first-pass approach. As a rather blunt instrument, it is reliable for some aspects of analysis, such as categorizing first person singular and plural, hedges, and verbal control, but it cannot distinguish between various uses of "you" (i.e., generic form, as a subject, as an object), nor can it identify the many nouns that serve as third-person subjects. Had we relied strictly on autocoding, we would have missed many of these aspects. Clauses, sorted based on automatically assigned codes, made human checks and corrections quick to perform. However, even with these aspects confidently coded, this does not provide a detailed picture of agency as it unfolds contextually and interactionally through language. This approach, therefore, is similar to that of Konopasky and Sheridan (2016), who emphasized that attending to intentionality of causation and autonomy provided diagnostics, situating these as useful tools in the larger interpretive process. In reviewing and making corrections that the auto-coding could not capture, we became more attuned to ways agency might be expressed as we considered possible variants speakers might have used. For instance, Shanti said "try it out" (**Figure 2**) and this is different from other statements she could have made. Had she said, "Try it out before our next meeting," we would see this as directive, removing control from the students, yet even the corrected, autocoded analysis would not detect this as different from her actual statement. Nonetheless, as another way into the data, the analysis of frequencies of hedges and of subjects and verbal control provided a means to consider the focal excerpts in their broader contexts, and to highlight segments of the transcripts that warrant more careful analysis. Future work using tools like these should remain cautious, not because of what they reveal, but because of what they could miss. In the interpretations of each except, we see the complexity of agency as it unfolds in the teams' language in use, but by using the autocoding technique, we binned together external actors—objects,

contexts of use, and stakeholders. This limited our inquiry into the varied roles of external actors and misses many nuances available in careful moment-by-moment interpretation.

Second, critics of quantification might note that we lack a defensible denominator for our analysis (Schegloff, 1993). We drew data from a small sample—three cases from one academic program at one university. While we acknowledge the ongoing conversation concerning the sufficiency of small samples (Boddy, 2016; Young & Casey, 2019) and width versus depth (Flick, 2018) in qualitative inquiry, we also support the widely accepted notion that decisions about which and how many cases are appropriate depend on the research questions guiding the study, such that "sampling decisions cannot be made in isolation" (Flick, 2018, p. 184). In our case, analyzing three relevant cases afforded depth of understanding and the ability to consider numerous commonalities across the teams. We gained greater clarity on the ways agency is contextualized *by* problem framing, as opposed to other kinds of decisions. With greater variety, these distinctions might not have been as clear. Yet, this also points to a need to expand broadly, to understand how transferrable or idiosyncratic these arguments may be. In particular, to build theory, studies that incorporate established constructs like professional identity formation may provide insight about the utility of framing agency as a construct.

Because our data were also drawn from cases where we no longer had a means to conduct member checking, we relied on the detailed cases that had been previously member checked. While the original data were selected with related goals and prior analysis conducted at another focal length, had we used the full data corpus, which includes, for instance, conversations about other courses, where to eat lunch, post-graduation plans, and so on, we may have lost focus on the moments most likely to show framing agency, or to show it differently. Future studies could contrast focused cases like those in this study to full corpus, and perhaps this could provide yet another contextualization of agency, as students certainly exercised their agency in many ways. The lack of additional member checking also limits our insight into students' perceptions of their agency and their roles as designers. We cannot know, for instance, how aware students were of their own responses to ill-structured problems. Future studies that document in-situ design work could include debriefs to investigate students' perceptions of decisions made and not made, their agency, and the perceived opportunity structure. Such debriefs could jointly provide triangulation of interpretations and, through reflective practice (Schön, 1983), foster in students a stronger sense of their own framing agency.

## Additional File

The additional file for this article can be found as follows:

- **Framing Agency Coding Tool.** This Excel spreadsheet provides instructions on how to conduct first-pass autocoding to quickly assess the presence of framing agency in design discourse. http://www.vanessasvihla.org/tools.html

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## Competing Interests

The authors have no competing interests to declare.

## Author Contributions

The first author collected all data, performed prior analysis, proposed the new construct of framing agency, and grounded the construct in the literature. The second author provided direction on discourse analysis and learner identity construction. The third author provided feedback on functional linguistic analysis and reviewed literature. All authors contributed to analysis and writing.

## References

Altshuller, G. (1996). *And suddenly the inventor appeared: TRIZ, the theory of inventive problem solving* (2nd ed.). Technical Innovation Center, Inc.

Atkinson, P., & Hammersley, M. (1994). Ethnography and participant observation. In N. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research, 1*, 248–261. Sage Publications.

Atman, C. J., Yasuhara, K., Adams, R. S., Barker, T. J., Turns, J., & Rhone, E. (2008). Breadth in problem scoping: A comparison of freshman and senior engineering students. *International Journal of Engineering Education*, *24*(2), 234–245. https://www.researchgate.net/profile/Robin_Adams/publication/233552110_Breadth_in_Problem_Scoping_a_Compar-

ison_of_Freshman_and_Senior_Engineering_Students/links/53eab52b0cf2fb1b9b6ac998/Breadth-in-Problem-Scoping-a-Comparison-of-Freshman-and-Senior-Engineering-Students.pdf.

Barlow, A. J., & Brown, S. (2020). Discovering upper-division students' cognitive engagement across engineering courses—An interpretive phenomenological analysis approach. *Studies in Engineering Education*, *1*(1), 58–73. DOI: https://doi.org/10.21061/see.5

Barr, R., Pandy, M. G., Petrosino, A. J., & Svihla, V. (2005, October 19–22). Challenge-based instruction in an engineering technical elective course. *Proceedings of ASEE/IEEE Frontiers in Education Conference*. http://aseegsw.com/past%20Proceedings/T4A3-Barr.pdf

Boddy, C. R. (2016). Sample size for qualitative research. *Qualitative Market Research: An International Journal*, *19*(4), 426–432. DOI: https://doi.org/10.1108/QMR-06-2016-0053

Bratman, M. E. (2013). *Shared agency: A planning theory of acting together*. Oxford University Press. DOI: https://doi.org/10.1093/acprof:oso/9780199897933.001.0001

Bucciarelli, L. (1999). Delta design: Seeing/seeing as. *Proceedings 4th Design Thinking Research Symposium on Design Representation*, 1–7. http://hdl.handle.net/1721.1/46334

Christiaans, H., & Almendra, R. A. (2010). Accessing decision-making in software design. *Design Studies*, *31*(6), 641–662. DOI: https://doi.org/10.1016/j.destud.2004.06.005

Cloward, R. A., & Ohlin, L. E. (1960). *Delinquency and opportunity: A theory of delinquent gangs*. The Free Press. DOI: https://doi.org/10.2307/2090685

Coyne, R. (2005). Wicked problems revisited. *Design Studies*, *26*(1), 5–17. DOI: https://doi.org/10.1016/j.destud.2004.06.005

Del Gaudio, C., Franzato, C., & de Oliveira, A. J. (2016). Sharing design agency with local partners in participatory design. *International Journal of Design*, *10*(1). http://www.ijdesign.org/index.php/IJDesign/article/view/2403/727

DeWalt, K. M., & DeWalt, B. R. (2010). *Participant observation: A guide for fieldworkers*. Rowman Altamira.

Dixon, J. A., & Foster, D. H. (1997). Gender and hedging: From sex differences to situated practice. *Journal of Psycholinguistic Research*, *26*(1), 89–107. DOI: https://doi.org/10.1023/A:1025064205478

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, *32*(6), 521–532. DOI: https://doi.org/10.1016/j.destud.2011.07.006

Dorst, K. (2019). Co-evolution and emergence in design. *Design Studies*, *65*, 60–77. DOI: https://doi.org/10.1016/j.destud.2019.10.005

Edwards, A. (2007). Relational agency in professional practice: A CHAT analysis. *Actio: An International Journal of Human Activity Theory, 1*, 1–17. https://core.ac.uk/download/pdf/228665665.pdf

Emirbayer, M., & Mische, A. (1998). What is agency? *American Journal of Sociology*, *103*(4), 962–1023. DOI: https://doi.org/10.1086/231294

Engeström, Y. (2008). *From teams to knots: Activity-theoretical studies of collaboration and learning at work*. Cambridge University Press. DOI: https://doi.org/10.1017/CBO9780511619847

Flick, U. (2018). *An introduction to qualitative research*. Sage. DOI: https://doi.org/10.4135/9781529716641

Fraser, M. W. (1996). Aggressive behavior in childhood and early adolescence: An ecological-developmental perspective on youth violence. *Social Work*, *41*(4), 347–361. DOI: https://doi.org/10.1093/sw/41.4.347

Gee, J. P. (2014). *An introduction to discourse analysis: Theory and method*. Routledge. DOI: https://doi.org/10.4324/9781315819679

Giddens, A. (1984). *The constitution of society: Outline of the theory of structuration*. University of California Press.

Ginwright, S., Cammarota, J., & Noguera, P. (2006). Sociopolitical development: The missing link in research and policy on adolescents. In S. Ginwright, P. Noguera, & J. Cammarota (Eds.), *Beyond resistance!: Youth activism and community change: New democratic possibilities for practice and policy for America's youth*. Routledge Taylor & Francis Group.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*, 5–26. DOI: https://doi.org/10.1037/0003-066X.53.1.5

Griffin, A., & Hauser, J. R. (1993). The voice of the customer. *Marketing Science*, *12*(1), 1–27. DOI: https://doi.org/10.1287/mksc.12.1.1

Harfield, S. (2007). On design 'problematization': Theorising differences in designed outcomes. *Design Studies*, *28*(2), 159–173. DOI: https://doi.org/10.1016/j.destud.2006.11.005

Hauser, J., & Clausing, D. (1988). The house of quality. *Harvard Business Review*, *66*(3), 63–73.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63–85. DOI: https://doi.org/10.1007/BF02300500

Kim, E., Purzer, S., Vivas-Valencia, C., & Payne, L. B. (2020). Problem reframing and empathy manifestation in the innovation process. *Proceedings of the ASEE Annual Conference*. DOI: https://doi.org/10.18260/1-2--35084

Kirn, A., & Benson, L. (2018). Engineering students' perceptions of problem solving and their future. *Journal of Engineering Education*, *107*(1), 87–112. DOI: https://doi.org/10.1002/jee.20190

Konopasky, A. W., & Sheridan, K. M. (2016). Towards a diagnostic toolkit for the language of agency. *Mind, Culture, and Activity*, *23*(2), 108–123. DOI: https://doi.org/10.1080/10749039.2015.1128952

Magnifico, C., & Defrancq, B. (2017). Hedges in conference interpreting: The role of gender. *Interpreting*, *19*(1), 21–46. DOI: https://doi.org/10.1075/intp.19.1.02mag

Mamaril, N. A., Usher, E. L., Li, C. R., Economy, D. R., & Kennedy, M. S. (2016). Measuring undergraduate students' engineering self-efficacy: A validation study. *Journal of Engineering Education*, *105*(2), 366–395. DOI: https://doi.org/10.1002/jee.20121

Markkanen, R., & Schröder, H. (1997). Hedging: A challenge for pragmatics and discourse analysis. In R. Markkanen & H. Schröder (Eds.), *Hedging and discourse: Approaches to the analysis of a pragmatic phenomenon in academic texts* (pp. 3–18). de Gruyter. DOI: https://doi.org/10.1515/9783110807332

McDonnell, J. (2018). Design roulette: A close examination of collaborative decision-making in design from the perspective of framing. *Design Studies*, *57*, 75–92. DOI: https://doi.org/10.1016/j.destud.2018.03.001

Merriam, S. B. (2007). *Qualitative research and case study applications in education*. Jossey-Bass.

Mirzapour, F. (2016). Gender differences in the use of hedges and first person pronouns in research articles of applied linguistics and chemistry. *International Journal of Applied Linguistics and English Literature*, *5*(6), 166–173. DOI: https://doi.org/10.7575/aiac.ijalel.v.5n.6p.166

Mohanani, R., Turhan, B., & Ralph, P. (2019). Requirements framing affects design creativity. *IEEE Transactions on Software Engineering*. DOI: https://doi.org/10.1109/TSE.2019.2909033

Mohedas, I., Daly, S. R., & Sienko, K. H. (2015). Requirements development: Approaches and behaviors of novice designers. *Journal of Mechanical Design*, *137*(7), 071407. DOI: https://doi.org/10.1115/1.4030058

Moje, E. B. (2000). "To be part of the story": The literacy practices of gangsta adolescents. *Teachers College Record*, *102*(3), 651–690. https://www.tcrecord.org/books/PrintContent.asp?ContentID=10517. DOI: https://doi.org/10.1111/0161-4681.00071

Morozov, A., Kilgore, D., & Atman, C. (2007). Breadth in design problem scoping: Using insights from experts to investigate student processes. *Proceedings of the ASEE Annual Conference*. DOI: https://doi.org/10.18260/1-2--2318

Murray, J. K., Studer, J. A., Daly, S. R., McKilligan, S., & Seifert, C. M. (2019). Design by taking perspectives: How engineers explore problems. *Journal of Engineering Education*, *108*, 248–275. DOI: https://doi.org/10.1002/jee.20263

Narayan, D., & Petesch, P. (2007). Agency, opportunity structure, and poverty escapes. In D. Narayan & P. Petesch (Eds.), *Moving Out of Poverty: Cross-Disciplinary Perspectives on Mobility* (pp. 1–44). The World Bank. DOI: https://doi.org/10.1596/978-0-8213-6991-3

Neeley, W. L., Jr., Lim, K., Zhu, A., & Yang, M. C. (2013). Building fast to think faster: exploiting rapid prototyping to accelerate ideation during early stage design. *ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. DOI: https://doi.org/10.1115/DETC2013-12635

Onarheim, B., & Biskjaer, M. M. (2017). Balancing constraints and the sweet spot as coming topics for creativity research. In L. J. Ball (Ed.), *Creativity in design: Understanding, capturing, supporting*. https://core.ac.uk/download/pdf/24848278.pdf

Pajares, F. (2005). Gender differences in mathematics self-efficacy beliefs. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics: An integrative psychological approach* (pp. 294–315). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9780511614446.015

Paton, B., & Dorst, K. (2011). Briefing and reframing: A situated practice. *Design Studies*, *32*(6), 573–587. DOI: https://doi.org/10.1016/j.destud.2011.07.002

Peele-Eady, T. B., & Moje, E. B. (2020). Communities as contexts for learning. In *Handbook of the cultural foundations of learning* (pp. 230–246). Routledge. DOI: https://doi.org/10.4324/9780203774977-16

Peräkylä, A. (2011). Validity in research on naturally occurring social interaction. In D. Silverman (Ed.), *Qualitative research* (pp. 365–382). Sage.

Petrosino, A. J., Martin, T., & Svihla, V. (Eds.). (2007). *Developing student expertise and community: Lessons from How People Learn* (Vol. 108). Jossey-Bass.

Pugh, S., & Clausing, D. (1996). *Creating innovtive products using total design: The living legacy of Stuart Pugh*. Addison-Wesley Longman Publishing Co., Inc.

Purcell, A. T., & Gero, J. S. (1996). Design and other types of fixation. *Design Studies*, *17*(4), 363–383. DOI: https://doi.org/10.1016/S0142-694X(96)00023-3

Reimlinger, B., Lohmeyer, Q., Moryson, R., & Meboldt, M. (2019). A comparison of how novice and experienced design engineers benefit from design guidelines. *Design Studies*, *63*, 204–223. DOI: https://doi.org/10.1016/j.destud.2019.04.004

Restrepo, J., & Christiaans, H. (2004). Problem structuring and information access in design. *Journal of Design Research*, *4*(2), 218–236. DOI: https://doi.org/10.1504/JDR.2004.009842

Russell, T. F., & Orbey, N. (1993). The technically feasible design. *Chemical Engineering Education*, *27*(3), 166–169. https://journals.flvc.org/cee/article/download/123763/122796

Schegloff, E. (1993). Reflections on quantification in the study of conversation. *Research on Language and Social Interaction*, *26*(1), 99–128. DOI: https://doi.org/10.1207/s15327973rlsi2601_5

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.
Sewell, W. H., Jr. (1992). A theory of structure: Duality, agency, and transformation. *American Journal of Sociology*, *98*(1), 1–29. DOI: https://doi.org/10.1086/229967
Shum, S. (1991). Cognitive dimensions of design rationale. In D. Diaper & N. V. Hammond (Eds.), *People and computers VI*. Cambridge University Press.
Siwatu, K. O. (2007). Preservice teachers' culturally responsive teaching self-efficacy and outcome expectancy beliefs. *Teaching and Teacher Education*, *23*(7), 1086–1101. DOI: https://doi.org/10.1016/j.tate.2006.07.011
Sterman, J. D. (1992). Teaching takes off. *OR/MS Today*, *35*(3), 40–44.
Svihla, V. (2009). Collaboration and framing as dimensions of design innovation. In N. Bryan-Kinns, M. D. Gross, H. Johnson, J. Ox, & R. Wakkary (Eds.), *Everyday Creativity Shared Languages and Collective Action: Proceedings of the seventh ACM conference on creativity and cognition* (pp. 285–294). ACM. DOI: https://doi.org/10.1145/1640233.1640276
Svihla, V. (2010a). Collaboration as a dimension of design innovation. *CoDesign: International Journal of CoCreation in Design and the Arts*, *6*(4), 245–262. DOI: https://doi.org/10.1080/15710882.2010.533186
Svihla, V. (2010b). Contingent identification in a biomedical engineering classroom. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Learning in the Disciplines, 1*, 913–920. International Society of the Learning Sciences. https://repository.isls.org//handle/1/2773
Svihla, V., Petrosino, A., Martin, T., Rayne, K., Rivale, S. R., & Diller, K. R. (2007). Distributed expertise and authenticity in the development of design expertise. In C. S. Furtado & M. d. G. Rasteiro (Eds.), *Proceedings of the International Conference on Engineering Education*. iNEER. http://icee2007.dei.uc.pt/proceedings/papers/387.pdf
Svihla, V., Petrosino, A. J., & Diller, K. R. (2012). Learning to design: Authenticity, negotiation, and innovation. *International Journal of Engineering Education*, *28*(4), 782–298. http://sites.utexas.edu/texas-bmes/files/2015/07/2012-Learning-to-Design-Authenticity-Negotiation-and-Innovation.pdf
Svihla, V., Petrosino, A. J., Martin, T., & Diller, K. R. (2009). Learning to design: Interactions that promote innovation. In W. Aung, K.-S. Kim, J. Mecsi, J. Moscinski, & I. Rouse (Eds.), *Innovations 2009: World Innovations in Engineering Education and Research* (pp. 375–391). International Network for Engineering Education and Research.
Tholander, J., Normark, M., & Rossitto, C. (2012). Understanding agency in interaction design materials. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2499–2508. https://dl.acm.org/doi/abs/10.1145/2207676.2208417?casa_token=dOKmBEt9gPEAAAAA:EfJIM7Ab-ACMnH07z4N03VHbP5wHsS61y-Q17gg0-dAm5PolpcWzigXXUC18tye7N1m4uqm1WsQJ
Walton, J. (1992). Making the theoretical case. In C. Ragin & H. Becker (Eds.), *What is a case?: Exploring the foundations of social inquiry* (pp. 121–138). Cambridge University Press.
Watkins, J., Spencer, K., & Hammer, D. (2014). Examining young students' problem scoping in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)*, *4*(1), 5. DOI: https://doi.org/10.7771/2157-9288.1082
Wood, L. A., & Kroger, R. O. (2000). *Doing discourse analysis: Methods for studying action in talk and text*. Sage.
Young, D. S., & Casey, E. A. (2019). An examination of the sufficiency of small qualitative samples. *Social Work Research*, *43*(1), 53–58. DOI: https://doi.org/10.1093/swr/svy026
Zahedi, M., & Heaton, L. (2017). A model of framing in design teams. *Design and Technology Education*, *22*(2). https://ojs.lboro.ac.uk/DATE/article/view/2264

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