Development and Insights from the Measure of Framing Agency

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Abstract

In this research paper, we report on our efforts to shed light on students' experiences of design problems. Our ongoing work investigates "framing agency," defined as making consequential decisions about how to frame design problems and proceed in learning and developing solutions. We previously characterized framing agency in design team talk using discourse analysis. The purpose of this study was to develop and test a measure of framing agency. Our prior analysis highlighted that due to a number of factors, students may or may not perceive opportunities to frame problems; framing agency may be individual or shared with others; students may or may not perceive their decisions as consequential; and students may or may not learn as a result of their and their teammates' decisions. Based on these dimensions, we developed an initial set of 52 items, which we then narrowed further based on expert review. We tested the items with students from three design-focused courses: a first-year course at a southwestern US research university (n=65) and two capstone senior courses (n=53 at the same southwestern research university and n=19 at a northern US research university). We conducted Exploratory Factor Analysis with a promax rotation and calculated Crohbach's Alpha to test internal reliability of related items. After removing low and cross loading items [1], we identified six latent dimensions covered by 18 items: individual consequentiality, shared consequentiality, learning as consequentiality, constrainedness, shared tentativeness / ill-structuredness, and individual tentativeness / ill-structuredness.

Introduction and research purpose

Undergraduate engineering programs have increasingly incorporated design projects, not just as first-year and capstone experiences, but in core courses as a spine [2-5]. However, there are many decisions to make in developing a design project and for those who lack the resources that are sometimes invested in capstone experiences, many limitations. For instance, design projects may include clients and specific context, or they may be kit- or competition-based. They may be deeply or shallowly connected to the course content. Students may all work on the same design brief or on several. This makes developing design projects that can support learning of content and design practices a complex problem. And, when a project does not support learning, it can be hard to know why. Research has suggested that a key factor is how students frame the problem, as this sets up how they will arrive at a design solution [6, 7]. Recent design-based research has also highlighted how design project configurations—including team structures, scaffolding, and authenticity—can support students to develop a sense of ownership over their design work and to display framing agency [8, 9]. Framing agency is defined as opportunities to make consequential decisions about design problems and ways to proceed in learning and developing solutions. This means that student teams make negotiated decisions that are consequential. Engineering designers who display framing agency know how to direct their design process, including when to take more time to better understand the problem, which in turn can result in higher quality, more creative solutions [6, 7]. Helping students develop and practice this capacity earlier means that when they enter the workplace, they will be more adept at a core professional practice.

While the construct of framing agency is promising, it has thus far been laboriously identified through discourse analysis. The purpose of this study, therefore, is to explore whether framing

agency may be measured efficiently as a set of scales. Specifically, the subscales detailed below in the literature review included the following: (1) Shared versus individual agency; (2) Ill-structuredness/tentativeness; (3) Constrainedness; and (4) Consequentiality. We sought to answer the following research questions:

1. Content validity: Which framing agency subconstructs do experts agree are relevant?
2. Quality assurance: Which framing agency constructs are identified using exploratory factor analysis (EFA)?

Literature review

We review research on the identified subscales of framing agency, which may be displayed as shared or individual decisions. Designers displaying framing agency do so in response to the ill-structured nature of design problems, and therefore know to remain tentative, even in the face of authentic constraints. As a result, their design decisions are consequential to both the problem space and their understanding of it and how to proceed.

Shared versus individual agency

Designers make many decisions— meaning they have agency [10]—in order to structure the problems they aim to solve because design problems do not arrive as tidy problems with a single correct answer [11, 12]. When making decisions, designers may share their agency in several ways. For instance, they may consider specific stakeholders, materials, and other designers. Accounts of decisions may even reveal both individual and shared agency. Consider, for instance, a team designing an algal biofuel plant, explaining “We choose the algal strain as a team, and it worked with sonication, which was my choice for harvesting algae.” Our goal is not to distinguish *between* these forms specifically, but rather to identify the presence of either/both.

Others have measured individual and shared agency in both generic terms and specific settings. For instance, in a study of supporting children with severe disabilities, researchers assessed whether service providers shared agency with family members by asking survey questions such as "Did the service provider listen to the child’s and the family’s wishes in implementing rehabilitation?" [13]. In the context of youth perceptions of parents sharing educational goals, shared agency was characterized as parents accommodating when they disagreed, collaborating, including to resolve disagreements, and supporting youth goals [14]. In these examples, there is a clear power differential at play, a difference that is not necessarily salient within design teams, but that is commonly present between student and instructor. However, power dynamics between student and instructor can shape student expectations for low agency, a situation most students have experienced in their coursework [15]. Building on these insights about agency, we define this subconstruct as the *extent to which an individual reports individual and/or team opportunity to make decisions*.

Ill-structuredness/Tentativeness

Design problems are ill-structured [16], meaning they have multiple possible problem frames and the problem co-evolves with the solution [17]. Researchers have even characterized the relationship between problem and solution as oscillatory [17, 18] and highly contingent [19]. In navigating this process, designers explore alternative, tentative solutions [20], a process that creates many opportunities to display framing agency. As a result, framing agency involves

being tentative about the problem. To assess this aspect of framing agency, we defined this subconstruct as the *extent to which an individual reports certainty about the design problem and solution*, with an assumption that, especially prior to completing a course-based design project, students who display framing agency will report uncertainty.

Constrainedness

Design problems have constraints but are not fully constrained [21]. Research suggests that compared to newcomers, experienced designers pay better attention to constraints as they frame and solve problems [22]. Constraints are variably salient depending on the designer's knowledge and goals; for instance, in a participant observation study that investigated how engineers and ergonomists contributed to a four-month design process, while some constraints were tied to the context and challenges managing the project with different design teams, other constraints were discipline-specific [23]. Designers often reframe problems as they deal with intractable, over-constrained aspects of problems [24, 25]. When a problem is too open, designers sometimes impose their own constraints [26, 27]. Viewed from the lens of agency, constraints contribute to the opportunity structure [28]—meaning whether there are opportunities to make decisions. Such opportunities, in learning settings, may also be constrained by learners' beliefs about their role as designers. Perceptions of constraints are therefore salient in understanding framing agency, and we define this subconstruct as the *extent to which an individual reports having opportunity to make decisions about the problem despite having design requirements or constraints.*

Consequentiality

Decisions about design problems may be consequential in various ways. First, when designers frame problems, they develop a sense of ownership over the problem [11, 29, 30], meaning making decisions can have consequences to their role. Designers gather information deliberately to address gaps in their own understanding [18] and clarify ambiguity, ruling out untenable solution paths [31], meaning that the decisions they make are consequential to their learning. And of course, when designers make consequential decisions, including how they will bound the problem [32], the decision alters not just the solution, but also the problem itself [17] and therefore the process to reach a solution [12, 17]. Experienced designers engage in framing and reframing deliberately and repeatedly, throughout their design process [33-37]. We define this subconstruct as the *extent to which an individual reports that the problem changed or their understanding changed as a result of decisions made individually or by the team, meaning that the decisions were consequential.*

Methods

This study involved the following stages: (1) item development based on review of literature and discourse analysis of design team talk; (2) expert review to validate content; and (3) exploratory factor analysis to validate items.

Item development and initial refinement

We followed best practices for survey development [38, 39]. Grounding survey items in theory and in data is central to developing questions that result in useful data [40, 41]. Therefore, to establish a set of potential subscales for measuring framing agency, we conducted a systematic review of research on agency and problem framing and related terms. While some distinguish

between terms such as problem scoping, problem framing, problem formulation, problem representation and problem definition, the terms are not used consistently across scholars. Many treat these terms as ambiguous and perhaps interchangeable; for instance, some scholars reference the findings of Atman and colleagues (who prominently refer to *scoping*) using the terms framing and scoping interchangeably [42]. Likewise, Atman and colleagues reference work by those who exclusively discuss *framing* [35, 43, 44], yet refer to that work as *scoping*.

We also reviewed related surveys. For instance, in the social sciences, researchers have developed surveys that measure empowerment and agency, and these surveys clarify that agency depends on having opportunities, actually making decisions, and dealing with the consequences of those decisions [10, 28]. We also drew upon a measure of project ownership in science [45, 46], as some questions addressed agency. Finally, we reviewed items from measures of shared agency conducted with students leaving home for college [14] and patients and medical practitioners [13].

We also grounded our questions in our past discourse analysis used to characterize framing agency [8, 9], an approach adapted from the linguistic agency toolkit [47]. This analysis, published elsewhere, investigated transcribed conversations between students on design teams from sophomore courses in chemical engineering, capstone design in biomedical engineering, high school design teams, and students in a non-engineering technical design undergraduate course. These analyses highlighted that framing agency is shared and tentative, even as students bring in understanding about constraints, and consequential to their understanding, the problem and their role as designers. Based our analysis of literature and our discourse analysis, we identified the potential subconstructs as shared versus individual agency, tentativeness and ill-structuredness, constrainedness, and consequentiality. We investigated these through post-observation structured interviews in a first year design course. An observer joined a team during design work and noted evidence of potential sub-constructs on observation protocol, then conducted a brief interview (e.g., “Did you, yourself, make any decisions today, related to your design project?”). We found that students reliably accounted for the decisions observed.

Based on these subconstructs, we developed Likert statements written as simple concepts [48] with a 7-point bipolar scale, with a middle option to reduce measurement error [49]. Research suggests that using item-specific scales, as opposed to the commonplace agree/disagree scale, can improve the quality of responses [50]; we thus avoided agree/disagree scales and focused on developing scales that reflected the construct we sought to measure. For instance, we avoided scales that focused on frequency (e.g., always to never), as in our discourse analysis, we observed that even infrequent decisions were sometimes very impactful. This resulted in scales that assessed amount (i.e., all or many to none, such as a teammate making decisions), certainty, freedom (i.e., to make decisions), responsibility, importance, and amount of problem change.

We expanded the set of possible questions, resulting in 52 possible questions (Table 1), including 1 constructed response item to assess the nature of the design project, 5 context questions to assess project characteristics (e.g., work completed as a team, duration), 4 constructed response questions to prompt students to consider specific design decisions and constraints encountered, prior to answering related Likert scaled questions, and 42 Likert-scaled questions. We reviewed kkkeach item multiple times, checking language clarity and reviewing the content against both prior analysis and relevant literature.

Content validity through expert review

We drafted materials for expert review, including a 1-page definition of framing agency and its sub-constructs, a version of the survey, and a scoring sheet. Given the relatively novel nature of the construct (e.g., as compared to developing a scale for self-efficacy in a new domain), we were concerned about the possibility of inclusion bias (i.e., in not having true expertise due to the newness of the construct, would experts tend to rate every question as relevant?). We developed 17 distractors to evaluate experts' tendency to include constructs that may be interesting but not included as subconstructs in the definition (Table 1). We

Table 1. Sample questions from the Framing Agency Survey, including distractors

Shared v. individual: Extent to which an individual reports individual and/or team opportunity to make decisions.	
Considering your design project, who made decisions? ● Did you personally make all, some, or none of the decisions related to your design project? ● Did someone else on your team make all, some, or none of the decisions related to your design project? ● Did you personally reject all, some, or none of the ideas others suggested related to your design project? ● Did someone else on your team reject all, some, or none of the ideas others suggested related to your design project?	● All ● Most ● Many ● Some ● Few ● Very Few ● None
Tentativeness & ill-structuredness: Extent to which an individual reports certainty about the design problem and solution.	
In the beginning [middle] of your project, how certain or uncertain did you feel that: ● you understood the design problem? ● your design project had a single right solution? ● you had to solve the problem as given to you? ● you had to just develop what was asked of you? ● you knew the optimal solution? ● your team could develop an acceptable solution?	● Very certain ● Certain ● Somewhat certain ● Neither certain nor uncertain ● Somewhat uncertain ● Uncertain ● Very uncertain
Constrainedness: Extent to which an individual reports having opportunity to make decisions about the problem despite having design requirements or constraints.	
Design problems typically have constraints, such as budget limitations, material properties, performance requirements, and other requirements set by the stakeholders and situations in which the design solution will be used. What were some constraints on the design problem you worked on?	Text box
Considering these constraints, how free or restricted: ● did you feel when making decisions yourself? ● did your teammates seem when making decisions?	● Very free ● Free ● Somewhat free ● Neither free nor restricted ● Somewhat restricted ● Restricted ● Very restricted

Consequentiality: Extent to which an individual reports that the problem changed or their understanding changed as a result of decisions made individually or by the team, meaning that the decisions were consequential.	
How responsible or not responsible did you feel: ● for making decisions personally? ● for making decisions as a team? ● for the outcomes of the design project? ● for coming up with your own ways to make progress on the design project?	● Very responsible ● Responsible ● Somewhat responsible ● Neither responsible nor not responsible ● Somewhat not responsible ● Not responsible ● Not at all responsible
Near distractors – for expert review only	
Considering your design project, what was easy or challenging for you? ● Ordering the design tasks. ● Locating information to solve the problem ● Agreeing on the appropriate solution ● Reporting on the solution	● Very easy ● Easy ● Somewhat easy ● Neither easy nor challenging ● Somewhat challenging ● Challenging ● Very challenging
Far distractors – for expert review only	
How interesting or uninteresting do you personally find this course as a whole?	● Very interesting ● Interesting ● Somewhat interesting ● Neither interesting nor uninteresting ● Somewhat uninteresting ● Uninteresting ● Very uninteresting

Six experts provided ratings for each survey item on a four-point scale (4=Very relevant, 1=Not relevant, following common practice [51]) as well as comments for many of the items. The experts are faculty in engineering or engineering education in U.S. universities. They are all designers and have taught design, and five have also conducted research on design. All six had experience developing, adapting, and using surveys in research, and one taught survey design. We calculated the content validity index (CVI) for each item and for the subscales, removing items with low CVI scores. Based on expert review, we refined the survey for pilot testing.

Quality assurance and subscale validation

Students in design-focused courses completed the survey near the end of a design project. This included students enrolled in a first-year course at a southwestern US research university (SRU,

n=65) and two capstone senior courses (n=53 at SRU and n=19 at a northern US research university [NRU]). As has been pointed out in the literature, recommended exploratory factor analysis (EFA) sample size is "varied, ambiguous, and often lacks validity" in part because some recommendations are based on tradition, and in part because sample size depends on multiple issues [52]. Some authors have argued that a sample size of 50 can suffice [53]. Assuming even moderate loading, our sample size will suffice [53]. Scale validity was assessed using standard procedures [40, 41]: first, by grounding the survey items in theory and in data; second, evaluating internal structure using exploratory factor analysis with a promax rotation [54]; and third, by testing the internal reliability of related items using Cronbach's alpha. We retained items provided they had loadings of at least .40 (dual loading items with greater than .35 on two or more factors were deleted [1, 55, 56]) and internal consistency of at least .50, using Cronbach's alpha [57]. We confirmed the sample correlation and adequacy using KMO (.60) and Bartlett's test of sphericity (χ^2 (153) = 519.60, p<0.01) [1].

Results and discussion

Content validation

Experts recognized a majority of the non-distractor items as relevant for measuring framing agency (Figure 1). They were equally as likely to suggest omitting near and far distractors, and consistently recommended excluding these items. We had included the distractors as a means to assess their understanding of framing agency, and conducted a t-test between the lowest average rated subscale and the highest rated distractor category, finding that experts were significantly more likely to agree that items in the Shared versus individual agency subscale should be included than in the near distractor set, $t(21) = 4.97$, $p < .001$, with a large effect size, (Cohen's $d = 2.08$). This result suggests that experts were able to effectively differentiate between the intended items and distractors. We therefore focus our remaining discussion on the intended items.

Experts' comments also indicated that they recognized subconstructs of framing agency in the survey items, such as taking ownership of a problem, the process of framing and re-framing a problem, and the shared, collaborative nature of framing agency. The full subscales did not meet the standard CVI cut score of 0.78 [51], (Shared versus Individual, CVI = 0.56; Constrainedness CVI = 0.61; Tentativeness/Ill -structuredness CVI = 0.75; Consequentiality CVI =0.50). Specifically, experts noted that several items appeared to measure teaming or team collegiality rather than measuring framing agency. This included, for instance, questions such as

- "My teammates let me do what I wanted when there were disagreements about an aspect of the design project."
- "To what extent did your teammates accept or reject your ideas when there were disagreements about an aspect of your design project?"
- "How collaborative or exclusionary were you and your teammates when negotiating the direction of your design project?"

We omitted such items that had low CVI scores. Experts varied in their assessments of the appropriateness of wording (clarity, word choice) of individual items. In some cases, one reviewer scored such items as not relevant, but indicated they would recommend retaining the item given a word change. While the typical CVI threshold with six reviewers is 0.78 [51], we

decided to retain such items if they otherwise received high scores from other reviewers. We additionally chose to retain two questions that asked students to report "How much or little did you learn as a result of decisions about the design problem [you personally made] / [a teammate made]?" Experts raised concerns, justifiably, about students' capacity to assess their own learning. As is documented in the literature, novices typically are not effective judges about what supports their learning [58]. However, we were not aiming to assess whether they *learned* as a result of making decisions, but the degree to which they experienced consequences, including feeling they had learned, as a result of making decisions.

This resulted in retaining 28 items (25 of which were Likert-scaled, Figure 2) in four subscales (Shared versus Individual agency, CVI = 0.77; Constrainedness CVI = 0.82; Tentativeness/Ill - structuredness CVI = 0.9; Consequentiality CVI =0.80).

Based on expert review, we modified terminology that we had questioned in the past. For example, we had been unable to choose between the terms restricting and limiting in a few items; experts' overall responses showed a slight preference for restricting.

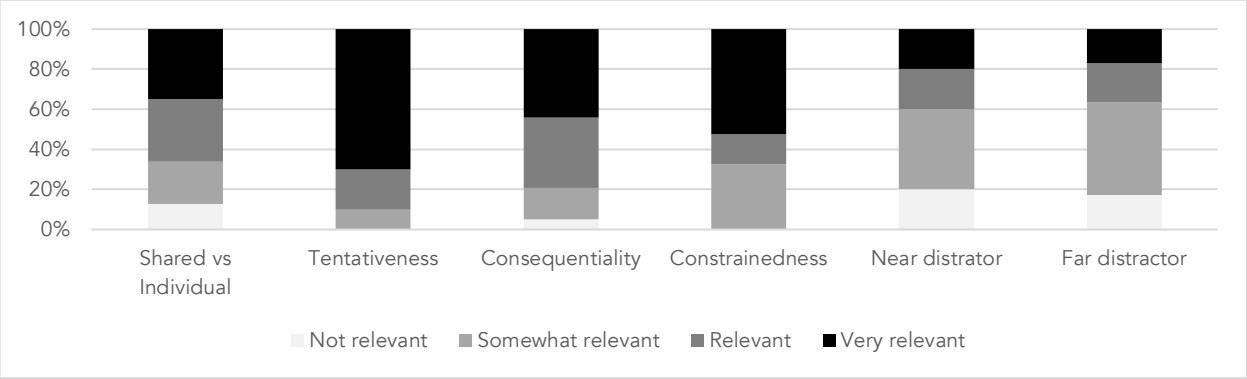

Figure 1. Ratings by experts of all questions by subconstruct and distractor type on a 4-point scale (4 = Very relevant; 3 = Quite relevant; 2 = Somewhat relevant; 1 = Not relevant).

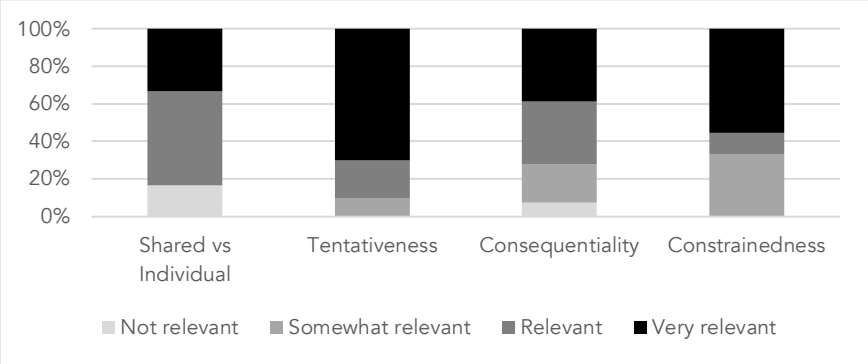

Figure 2. Ratings by experts of retained questions by subconstruct

Quality assurance

We conducted the exploratory factor analysis (EFA) with the 25 Likert-scaled items (Table 2). After removing low and cross loading items [1], we identified six latent dimensions: Individual consequentiality (α = 0.85); shared consequentiality (α = .77); learning as consequentiality (α =

0.78); constrainedness (α = 0.79); shared tentativeness / ill-structuredness (α = 0.81); and individual tentativeness / ill-structuredness (α = .56).

Table 2. Exploratory Factor Analysis results

Item prompt	*Factor Loading*						*Mean (SD)*	*α if deleted*
Factor: Individual Consequentiality ***(α = 0.85)***								
How responsible or not responsible did you feel for the outcomes of the design project?	0.78	-0.1	0.1	0.16	-0.06	0.04	6.01 (0.80)	0.8
Considering the decision you described, how important or unimportant was the decision?	0.78	0.13	-0.13	-0.08	0.08	-0.1	5.95 (1.02)	0.82
Considering the decision you described, how important or unimportant was the impact of that decision on your design process?	0.76	0.2	-0.08	-0.02	0.04	-0.05	5.95 (1.02)	0.82
How responsible or not responsible did you feel for making decisions personally?	0.7	-0.17	0.07	0.02	-0.04	0.05	5.79 (0.94)	0.82
How responsible or not responsible did you feel for coming up with your own ways to make progress on the design project?	0.66	-0.07	0.05	-0.1	-0.07	0.1	5.71 (0.91)	0.82
Factor: Shared Consequentiality ***(α = 0.77)***								
Considering the decision you described, how important or unimportant was the impact of that decision on your design process?	-0.05	0.88	0.06	-0.03	-0.1	0.1	6.23 (0.70)	-
Considering the decision you described, how important or unimportant was the decision?	0.06	0.74	-0.01	0.01	0.02	0.02	6.32 (0.51)	-
Factor: Learning as Consequentiality ***(α = 0.78)***								
How much or little did you learn as a result of decisions about the design problem a teammate made?	-0.1	0.07	0.88	0.03	0	0	5.61 (1.04)	-
How much or little did you learn as a result of decisions about the design problem you personally made?	0.13	-0.02	0.73	-0.07	0.04	-0.05	5.56 (0.95)	-
Factor: Constrainedness ***(α = 0.79)***								
Considering these constraints, how free or restricted did your teammates seem when making decisions?	-0.03	0.01	0.05	0.95	0.03	-0.02	4.87 (1.20)	0.57
Considering these constraints, how free or restricted did you feel when making decisions yourself?	0.04	-0.01	0.01	0.91	0	0.07	4.73 (1.25)	0.56
How free or limiting did the design problem seem to be?	-0.07	-0.11	-0.04	0.42	-0.06	0.07	4.84 (1.27)	0.94
Factor: Shared tentativeness / Ill-structuredness ***(α = 0.81)***								
How certain or uncertain do you feel that you have to solve the problem as given to you?*	0	-0.07	-0.1	0.06	0.84	-0.04	3.36 (0.96)	0.72
How certain or uncertain do you feel that your design project has a single right solution?*	0.01	0.01	0.01	-0.07	0.74	0.24	4.66 (1.16)	0.78
How certain or uncertain do you feel that you have to just develop what was asked of you?*	-0.02	-0.05	0.01	0.71	0.71	-0.01	3.54 (1.07)	0.76
How certain or uncertain do you feel that you know the optimal solution?*	-0.01	0.15	0.05	0.62	0.62	-0.01	4.33 (1.69)	0.78
Factor: Individual tentativeness / ill-structuredness ***(α = 0.56)***								
How certain or uncertain do you feel that you understand the design problem?	-0.03	0.06	-0.04	0	0.05	0.71	6.07 (0.67)	-

Considering your design project, did you have many or few opportunities to make decisions as a team related to your design project?	0.05	0.1	0	0.1	0.07	0.53	5.31 (0.92)	-

*Reversed items

Discussion, significance & implications

First we conducted content validation. We found that experts differentiated between distractor questions, regardless of whether they were near or far distractors, and questions intended to measure framing agency subscales. They additionally noted that that several questions focused on team dynamics rather than framing agency, and provided feedback about word choice improvements. By removing items rated as not relevant, we developed a measurement of framing agency with four proposed subscales with moderately high content validity. Given the novelty of the construct of framing agency, we chose to retain a items tied to aspects of consequentiality related to perceptions that they had learned, but that did not meet the typical standard.

We then followed quality assurance procedures, testing the survey with students from three design-focused courses at two universities that serve very different populations. Using EFA, we identified six factors: individual consequentiality; shared consequentiality; learning as consequentiality; constrainedness; shared tentativeness / ill-structuredness; and individual tentativeness / ill-structuredness. Thus, we broadly found support that all subconstructs mattered in measuring framing agency. Our EFA results align to past research on framing agency that have characterized it as involving both individual and shared aspects, making consequential decisions that affect the design problem and involve learning, and staying tentative about both problem and solution [8, 9]. Grounded in research on design as an ill-structured process [16] in which the problem co-evolves with the solution [17], designers use their agency to make many tentative and consequential decisions [20].

However, we also found that shared versus individual agency intersected with other subconstructs. Specifically, our results suggest that consequentiality and tentativeness/ill-structuredness tended to include both individual and shared versions. We consider this result in light of the research literature.

Past efforts to measure shared agency have focused on power dynamics involved, not on ways shared agency impacts other contextual aspects of agency. However, the results of these studies have suggested that shared agency matters when understanding consequentiality. For instance, in a study that investigated whether parents and children's wishes were taken into account when formulating a rehabilitation plan for the child, when parents perceived that such wishes were taken into account—meaning, they had some sense of shared agency—they were more satisfied that their child's needs were being met—meaning, they viewed their input as consequential [13]. From a framing agency lens, we might consider *formulating a rehabilitation plan* as framing a problem and consider the medical team akin to designers. In light of modern views of medical practice as involving interprofessional teams that include patients, we might also consider the parent and child as part of the design team. From this point of view, shared agency and consequentiality are clearly related.

Likewise, research on parents' shared versus non-shared agency in formulating various goals (e.g., education, career, marriage) for their children demonstrates variability by goal type [59],

suggesting that the degree to which agency is shared may be contextual. They also found that parent who reported shared agency tended to report satisfaction with their children's education and their relationship with their children. This also suggests a relationship between shared agency and consequentiality.

Our findings therefore extend work on shared agency and consequentiality, highlighting a role for individual agency. Past research on this area has primarily focused on situations with clear power imbalances, such as between a medical practitioner and patient or parent and child. In our context, power dynamics are certainly not absent, but are less bimodal, more multifaceted (e.g., team members may navigate intersectional power dynamics related to their various demographic identities, as well as their standing in their program and salient experience with the problem).

It is also unsurprising to find that consequentiality itself is multidimensional, given that framing agency has been characterized as consequential to both the design problem and the designer's understanding of it [8, 9]. Design problem framing involves learning about problems [18] in order to shape and bound them [32]. As designers work on teams, they may learn from their own and others' efforts, suggesting that perception of learning, while sourced from both individual and/or team efforts, is an individual consequence. In other words, perceptions of having learned as a consequence of decisions centers the individual. Extending this to measure an individual's perception that their teammates also learned, or that they learned together would reveal more about team functioning that consequentiality. Future research using the framing agency survey will investigate whether differences in team member perceptions of learning as consequentiality explain variance in other team-level outcomes.

Given that both tentativeness/ill-structuredness and consequentiality had both individual and shared aspects, we were curious to note that constrainedness did not. This may reflect that, as the study included only student designers, they tended to view constraints as tied to the problem. Future research could include experienced designers, who may differentiate between their own and other's capacity to introduce new constraints [26, 27] or relax existing constraints [24, 25]. This may require additional questions that more carefully probe these as individual and shared efforts. To better understand this process with newcomers, however, more research may be needed on how newcomers perceive constraints, as constraints appear to be domain-specific [23]. Our future work will contribute to this by analyzing the kinds of constraints students reported in the constructed response items that were intended to contextualize their evaluations of constraints.

Based on our analysis, we refine the subconstructs of framing agency as

- Individual consequentiality: extent to which an individual reports that the problem changed as a result of decisions made individually, meaning that their own decisions were consequential
- Shared consequentiality: extent to which an individual reports that the problem changed as a result of decisions made by the team, meaning that other's decisions were consequential
- Learning as consequentiality: extent to which an individual reports that their understanding changed as a result of decisions made individually or by the team, meaning that the decisions were consequential

- Constrainedness: extent to which an individual reports having opportunity to make decisions about the problem despite having design requirements or constraints.
- Shared tentativeness / ill-structuredness: extent to which an individual reports their team's treatment of the design problem as tentative and ill-structured
- Individual tentativeness / ill-structuredness: extent to which an individual reports their understanding of the design problem as tentative and ill-structured

Our analysis has provided evidence that the framing agency survey provides valid information about the extent to which an individual experienced framing agency in a design-focused course. While future studies can provide additional evidence on the stability of our results, our findings are promising and suggest that instructors may use the survey as an efficient means to evaluate whether students perceive opportunities to use and develop their capacity to make consequential decisions in framing design problems. The results from such use may also inform instructors' project selection in subsequent courses. In addition, researchers may use the survey to expand and accelerate framing agency research. Future research can focus on the kinds of experiences that foster the development of framing agency and link framing agency to other kinds of outcomes, such as professional identity formation, learning, and intent to persist.

Limitations

While the total sample size (N=137) is still somewhat underpowered, our results provided promising insight into framing agency subconstructs. The minimum sample size for EFA is a long-standing discussion [60], and different scholars suggest different methods and ratios between items and case such as 3:1, 5:1, or 20:1 [61]. Our sample ratio is 5.7:1, which is acceptable; however, a larger sample size for EFA would provide more stable results. Future research will expand this sample size, allowing us to examine the stability of identified factors.

With sufficient additional cases, we will conduct a confirmatory factor analysis with the related validity tests (convergent, discriminant, and criterion-related validities) to confirm the framing agency measurement.

Our research thus far has only investigated framing agency in learning settings. Given that many studies have identified differences in how experienced designers, compared to newcomers direct their design process, [33-37] our future work will extend this construct to practicing designers to elucidate aspects of framing agency that are salient either only in practice or learning settings. Future work will also compare survey results and discourse analysis results from the same groups of students as an additional method of survey validation.

Finally, our study participants have included only chemical, biomedical, and mechanical engineers. Future research will expand this to other engineering disciplines.

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References

[1] J. F. Hair, W. C. Black, B. J. Babin, R. E. Anderson, and R. L. Tatham, *Multivariate data analysis*. Upper Saddle River, NJ: Pearson Prentice Hall, 2006.

[2] Z. S. Roth, H. Zhuang, V. Ungvichian, and A. Zilouchian, "Integrating Design into the Entire Electrical Engineering Four Year Experience."

[3] B. I. Hyman, "From capstone to cornerstone: A new paradigm for design education," *International Journal of Engineering Education,* vol. 17, no. 4/5, pp. 416-420, 2001.

[4] E. T. Morris and D. McAdams, "A Review of Practical Design Integration Methods for Existing Engineering Curriculum," *Proceedings of ASEE Annual Conference & Exposition,* 2015.

[5] K. Lulay, H. Dillon, T. A. Doughty, D. S. Munro, and S. Z. Vijlee, "Implementation of a design spine for a mechanical engineering curriculum," 2015.

[6] J. W. Getzels, "Problem-finding and the inventiveness of solutions," *The Journal of Creative Behavior,* vol. 9, no. 1, pp. 12-18, 1975.

[7] R. Mohanani, B. Turhan, and P. Ralph, "Requirements Framing Affects Design Creativity," *arXiv preprint arXiv:1902.11278,* 2019.

[8] V. Svihla, J. R. Gomez, M. A. Watkins, and T. B. Peele-Eady, "Characterizing framing agency in design team discourse," in *Proceedings of the ASEE 126th Annual Conference and Exhibition*: ASEE, 2019.

[9] V. Svihla, T. B. Peele-Eady, and Y. Chen, "Agency in framing design problems " in *AERA Annual Meeting*, Toronto, ON, Canada, 2019.

[10] R. Alsop, M. F. Bertelsen, and J. Holland, *Empowerment in practice: From analysis to implementation*. Washington, DC: World Bank Publications, 2006.

[11] J. Restrepo and H. Christiaans, "Problem Structuring and Information Access in Design," *Journal of Design Research,* vol. 4, no. 2, pp. 218–236, 2004.

[12] D. A. Schön, *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books, 1983.

[13] A. Järvikoski, M. Martin, I. Autti-Rämö, and K. Härkäpää, "Shared agency and collaboration between the family and professionals in medical rehabilitation of children with severe disabilities," *International Journal of Rehabilitation Research,* vol. 36, no. 1, pp. 30-37, 2013.

[14] E. S. Chang, J. Heckhausen, E. Greenberger, and C. Chen, "Shared agency with parents for educational goals: Ethnic differences and implications for college adjustment," *Journal of Youth and Adolescence,* vol. 39, no. 11, pp. 1293-1304, 2010.

[15] V. Svihla and R. Reeve, "Facilitating problem framing in PBL classrooms," *Interdisciplinary Journal of Problem-based Learning,* vol. 10, no. 2, 2016.

[16] D. H. Jonassen, "Toward a Design Theory of Problem Solving," *Educational Technology Research and Development,* vol. 48, no. 4, pp. 63-85, 2000.

[17] K. Dorst and N. Cross, "Creativity in the design process: co-evolution of problem-solution," *Design Studies,* vol. 22, no. 5, pp. 425-437, 2001.

[18] P. Tracy, "Design and Problem Finding in High Schools: A Study of Students and Their Teacher in One Queensland School," Masters, Education, Griffith University, 2005.

[19] S. Schrader, W. M. Riggs, and R. P. Smith, "Choice over uncertainty and ambiguity in technical problem solving," *Journal of Engineering and Technology Management,* vol. 10, no. 1, pp. 73-99, 1993.

[20] A. Morozov, D. Kilgore, and C. Atman, "Breadth in design problem scoping: Using insights from experts to investigate student processes," in *American Society for Engineering Education Annual Conference and Exposition*, 2007.
[21] M. D. Gross, "Design as exploring constraints," Citeseer, 1985.
[22] L. L. Bogusch, J. Turns, and C. J. Atman, "Engineering design factors: how broadly do students define problems?," in *Frontiers in Education Conference*, Kansas City, MO, 2000, vol. 2.
[23] C. M. Burns and K. J. Vicente, "A participant-observer study of ergonomics in engineering design:: how constraints drive design process," *Applied Ergonomics,* vol. 31, no. 1, pp. 73-82, 2000.
[24] W. R. Reitman, "Heuristic decision procedures, open contraints, and the structure of ill-defined problems," in *Human Judgements and Optimality*, G. Bryan, Ed. New York: John Wiley, 1964.
[25] N. Cross, "Designerly Ways of Knowing: Design Discipline Versus Design Science," *Design Issues,* vol. 17, no. 3, pp. 49-55, 2001.
[26] M. Mose Biskjaer and K. Halskov, "Decisive constraints as a creative resource in interaction design," *Digital Creativity,* vol. 25, no. 1, pp. 27-61, 2014.
[27] B. Onarheim, "Creativity from constraints in engineering design: lessons learned at Coloplast," *Journal of Engineering Design,* vol. 23, no. 4, pp. 323-336, 2012.
[28] D. Narayan and P. Petesch, "Agency, opportunity structure, and poverty escapes," *Moving Out of Poverty: Cross-Disciplinary Perspectives on Mobility,* pp. 1-44, 2007.
[29] A. Newell and H. A. Simon, *Human problem solving* (no. 9). Prentice-Hall Englewood Cliffs, NJ, 1972.
[30] D. A. Schön, *Educating the reflective practitioner*. San Francisco: Jossey-Bass, 1987.
[31] M. Basadur, G. B. Graen, and S. G. Green, "Training in creative problem solving: Effects on ideation and problem finding and solving in an industrial research organization," *Organizational Behavior and Human Performance,* vol. 30, no. 1, pp. 41-70, 1982.
[32] C. J. Atman, K. Yasuhara, R. S. Adams, T. J. Barker, J. Turns, and E. Rhone, "Breadth in Problem Scoping: a Comparison of Freshman and Senior Engineering Students," *International Journal of Engineering Education,* vol. 24, no. 2, pp. 234-245, 2008.
[33] M. Zahedi, L. Heaton, M. Guité, G. De Paoli, and M. Reumont, "Exploring framing within a team of industrial design students," 2016: DRS2016, Design Research Society 50th Anniversary Conference, Future-Focused Thinking, Brighton, UK.
[34] R. Valkenburg and K. Dorst, "The reflective practice of design teams," *Design Studies,* vol. 19, no. 3, pp. 249-271, 1998.
[35] D. A. Schön, "Designing: Rules, types and words," *Design studies,* vol. 9, no. 3, pp. 181-190, 1988.
[36] S. Ahmed, K. M. Wallace, and L. T. Blessing, "Understanding the differences between how novice and experienced designers approach design tasks," *Research in Engineering Design,* vol. 14, no. 1, pp. 1-11, 2003.
[37] M. Mehalik and C. Schunn, "What constitutes good design? A review of empirical studies of design processes," *International Journal of Engineering Education,* vol. 22, no. 3, p. 519, 2007.
[38] D. A. Dillman, J. D. Smyth, and L. M. Christian, *Internet, Phone, Mail and Mixed-Mode Surveys: The Tailored Design Method*. Hoboken, NJ: Wiley, 2016.

[39] D. B. McCoach, R. K. Gable, and J. P. Madura, "Instrument development in the affective domain," *Social and Corporate Applications: Springer,* 2013.
[40] R. F. DeVellis, *Scale development: Theory and applications*. Sage publications, 2016.
[41] R. G. Netemeyer, W. O. Bearden, and S. Sharma, *Scaling procedures: Issues and applications*. Sage Publications, 2003.
[42] C. Williams, J. Gero, Y. Lee, and M. Paretti, "Exploring the Effect of Design Education on the Design Cognition of Sophomore Engineering Students," in *Proceedings of ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*Washington, DC: ASME, 2011, pp. 607-614.
[43] N. Cross and A. Clayburn Cross, "Expertise in engineering design," *Research in Engineering Design,* vol. 10, no. 3, pp. 141-149, 1998.
[44] N. Cross, "Design cognition: Results from protocol and other empirical studies of design activity," in *Design knowing and learning: Cognition in design education*, vol. 5, C. M. Eastman, W. M. McCracken, and W. C. Newstetter, Eds. Oxford, UK: Elsevier Science, 2001, pp. 79-103.
[45] D. I. Hanauer and E. L. Dolan, "The project ownership survey: measuring differences in scientific inquiry experiences," *CBE-Life Sciences Education,* vol. 13, no. 1, pp. 149-158, 2014.
[46] D. I. Hanauer, M. J. Graham, and G. F. Hatfull, "A Measure of College Student Persistence in the Sciences (PITS)," *CBE-Life Sciences Education,* vol. 15, no. 4, p. ar54, 2016.
[47] A. W. Konopasky and K. M. Sheridan, "Towards a Diagnostic Toolkit for the Language of Agency," *Mind, Culture, and Activity,* vol. 23, no. 2, pp. 108-123, 2016.
[48] E. E. Ruel, W. E. Wagner III, and B. J. Gillespie, *The Practice of Survey Research*. Sage, 2015.
[49] C. O'Muircheartaigh, J. A. Krosnick, and A. Helic, "Middle alternatives, acquiescence, and the quality of questionnaire data," *Annu. Meet. Am. Assoc. Public Opin. Res., Fort Lauderdale, FL,* 2000.
[50] W. Saris, M. Revilla, J. A. Krosnick, and E. M. Shaeffer, "Comparing questions with agree/disagree response options to questions with item-specific response options," in *Survey Research Methods*, 2010, vol. 4, no. 1, pp. 61-79.
[51] M. R. Lynn, "Determination and quantification of content validity," *Nursing research,* vol. 35, no. 6, pp. 382-386, 1986.
[52] T. A. Schmitt, "Current methodological considerations in exploratory and confirmatory factor analysis," *Journal of Psychoeducational Assessment,* vol. 29, no. 4, pp. 304-321, 2011.
[53] J. d. de Winter, D. Dodou, and P. Wieringa, "Exploratory factor analysis with small sample sizes," *Multivariate behavioral research,* vol. 44, no. 2, pp. 147-181, 2009.
[54] J. W. Osborne, A. B. Costello, and J. T. Kellow, "Best practices in exploratory factor analysis," *Best practices in quantitative methods,* pp. 86-99, 2008.
[55] A. B. Costello and J. W. Osborne, "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis," *Practical assessment, research & evaluation,* vol. 10, no. 7, pp. 1-9, 2005.
[56] M. A. Pett, N. R. Lackey, and J. J. Sullivan, *Making sense of factor analysis: The use of factor analysis for instrument development in health care research*. Thousand Oaks, CA: Sage, 2003.

[57] L. J. Cronbach, "Coefficient alpha and the internal structure of tests," *psychometrika,* vol. 16, no. 3, pp. 297-334, 1951.
[58] P. A. Kirschner and J. J. G. van Merriënboer, "Do Learners Really Know Best? Urban Legends in Education," *Educational Psychologist,* vol. 48, no. 3, pp. 169-183, 2013.
[59] E. S. Chang and B. Lee, "Parenting goals and perceived shared and non-shared agency among kirogi mothers of a youth," *International Journal of Adolescence and Youth,* vol. 22, no. 4, pp. 470-483, 2017.
[60] R. C. MacCallum and L. R. Tucker, "Representing sources of error in the common-factor model: Implications for theory and practice," *Psychological Bulletin,* vol. 109, no. 3, p. 502, 1991.
[61] B. Williams, A. Onsman, and T. Brown, "Exploratory factor analysis: A five-step guide for novices," *Australasian Journal of Paramedicine,* vol. 8, no. 3, 2010.