Sparking Reflexivity: Data Generation Methods and Recommendations for Eliciting Complex Belief Sets in Engineering Education Research

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Introduction

In this full methods paper, we discuss data generation methods and considerations for eliciting complex belief sets in engineering education research.

Engineering work is inherently sociotechnical as it addresses challenges that involve an understanding of the interplay between societal needs and technical knowledge [1]. As such, progress on society's most pressing and complex problems requires the collective contributions of diverse stakeholders: both engineers and non-engineers (in which both groups include individuals from a broad range of backgrounds, contexts, and perspectives) [2]. Yet, the professional socialization of engineering students fosters the belief that engineers' scientific approaches to problem solving are superior to other ways of thinking. The belief sets that undergird engineers as superior problem solvers are fostered implicitly via a complex socialization process [3], [4], [5], and as such, people need explicit opportunities to reflect on and learn to be critical of such beliefs, a process known as reflexivity [6]. We argue that the socialization of engineers that endorses a belief in the superiority of their perceptions as engineers is a barrier to their ultimate ability to contribute to socio-technical challenges in egalitarian ways. Engineering education must develop approaches that facilitate reflexive awareness to promote egalitarian ways while combatting this socialization in settings where sociotechnical problem solving is taught, otherwise we will continue to implicitly promote an engineering culture steeped in myths of objectivity, neutrality, and meritocracy. Methods to **study complex belief sets in engineering are an important yet under-explored way to enable individual-level reflexivity and disrupt the status quo.**

Background

Research on beliefs continues to advance as beliefs are increasingly recognized as an important construct across various research domains and disciplines. Beliefs may be defined as "part of a system that includes values and attitudes, plus personal knowledge, experiences, opinions, prejudices, morals, and other interpretive perceptions of the social world" [7]. Beliefs serve as the foundation for how we understand our experiences, providing researchers a lens for how we experience the world and what informs our conduct in real-world settings [8], [9], [10], [11]. Furthermore, beliefs play an important role in culture and social systems by serving as group norms and values, which are transmitted socially [10], [11], [12], [13]. It has even been argued that beliefs are the most valuable psychological construct to study in education because of the insight they provide into behavior [10].

The study of beliefs is particularly challenging because they exist in complex ways: they are often nested (e.g., interrelated) and may be aspirational but not enacted (e.g., an espoused value that is misaligned with behavior), and may exist at varying levels of individual salience [14]. Further, belief sets are not necessarily coherent or internally consistent [9], [12], [13]. For example, when studying the beliefs of a teacher in training, Bryan [14] found that while the teacher had aspirational beliefs related to the teacher's role as a guide or facilitator in the classroom, her foundational belief of teacher as authority whose role was to direct, tell, and explain (rooted in her lived experience) showed up in her behavior. As a result of these existing complexities, theoretical and methodological approaches to studying beliefs have diversified to better surface and understand the complexity of belief sets. Our work aims to contribute to the methodological tools available to study beliefs in the context of engineering education.

We posit that developing methods that engage the interviewer and participant in collaborative sensemaking to elicit complex belief sets can enable engineering students to practice reflexivity. Practicing reflexivity is a way for individuals to gain insight on how their personal beliefs inform their behavior. Robbins [6] specifically calls for engineers to be "reflexive," meaning they must be able to constantly reflect on how their beliefs and assumptions inform their approaches and behaviors and act in ways that integrate the outcome of that critical reflection. When engineers are reflexive, they can engage in advanced ethical reasoning that considers multiple perspectives [15], and provide more effective contributions to complex, sociotechnical problems [16], [17].

Our current work seeks to share our insights and recommendations for adapting three different data generation methods for the purpose of eliciting complex belief sets to enable reflexivity. Reflexivity is largely internal- while reflexive practices can be facilitated with external support, the individual must choose to engage deeply with their own beliefs and assumptions to practice reflexivity [6], [18]. Thus, collaborative methods are critical for reflexivity because surfacing beliefs and engaging in sensemaking around beliefs must be done internally (but may be supported externally) by the person who wishes to be reflexive. While in this phase of our research (larger study context is described below) we are focused on understanding and eliciting complex belief sets, our ultimate goal is to transition the data generation methods we are developing into instructional tools for reflexivity. Thus, the data generation methods we discuss in this paper are designed to engage the participant in collaborative sensemaking with the interviewer about their beliefs and assumptions.

Larger context of our current work

We situate our exploration of these data generation methods in our work on enabling reflexivity in the context of engineering service-learning. This work is a subset of a larger National Science Foundation supported research project (NSF #2327938). In our larger study, our goal is to develop classroom interventions engineering service-learning instructors and students can utilize to promote reflexivity regarding their beliefs about the relative value of diverse perspectives. To this end, we have first adapted methods from various social science disciplines to elicit complex beliefs in an engineering education research context. We intend to work collaboratively with engineering service-learning instructors to translate these adapted methods into a classroom context and ultimately produce instructional interventions to enable reflexivity in engineering service-learning contexts regarding the value of diverse perspectives.

Conceptual framework

Sociotechnical dualism is the anchor which scopes and informs our beliefs research. Building on work out of science and technology studies and the sociology of engineering, Robbins [16] describes and contrasts characteristics of traditional vs. reflexive (sociotechnical) engineers (Table 1), ultimately arguing that reflexive engineers are better equipped to address sociotechnical challenges because they integrate broader social concerns into their work and actively value the community and environment they work with integrated with their technological contributions. As our ultimate research goal is to enable engineering service-learning students to practice reflexivity about the value of diverse perspectives, Robbins' [6] description of reflexive engineers has informed our methods development by serving as an anchor for the categories of belief sets we are trying to elicit. In other words, we are grounding our methods in the goal of eliciting complex beliefs regarding the value of diverse perspectives specifically on the spectrum of sociotechnical engineering. By spectrum of sociotechnical engineering, we mean the different degrees to which engineers engage social and technical knowledge, dynamics, and considerations in different aspects of their engineering practice. To adapt the methods discussed below to elicit different belief sets than those in our work, it is necessary to select a conceptual framework to anchor the method adaptation and scope the belief sets under investigation.

Table 1. Traditional and reflexive engineers compared, from [6]

	Traditional engineers	**Reflexive engineers**
Technology/society relationship	Technological shaping of society	Socio-technical dynamics
Perception of lay technical competence	Public dearth of understanding	Public is a knowledge resource
Means of making decisions	Experts 'engage' and educate the public	Public/expert dialogue and agreement
View of development	Technologically driven	Livelihoods based
Technological uptake	Experts communicating to the public brings acceptance of technology	Social, economic, and environmental factors explain why technologies are adopted or rejected
Politics of knowledge	Engineers know best	Engineer/stakeholder partnership
Epistemological approach to problems and solutions	Technical specialization	Complex systems
View of expertise	Narrow, discipline-based	Broad and holistic, interdisciplinary
Conceptual starting point	Designs	Socio-technical systems

Description of data generation methods

In the following sections, we provide background for each data generation method before discussing considerations for adapting the methods to an engineering education and beliefs research context. We briefly review the origins and uses of each method in various disciplines how each method has previously been used in engineering education research, and a brief justification for why the method is promising for eliciting complex belief sets. Note that in this paper, each data generation method is intended to be implemented separately for separate participants (e.g., one participant may participate in a vignette interview session, another in photo elicitation, etc.) as three different ways to generate data.

Vignettes

While the word vignette is often used synonymously with scenario or anecdote, in this paper, a vignette refers to a short story about hypothetical people [19]. Vignettes are a research technique originating in sociology and used in a wide array of disciplines, including sociology, healthcare research, and engineering education [19], [20], [21], [22], [23]. Additionally, vignettes can be used to meet various research goals, such as in survey research to study beliefs about family obligation [24], qualitative research to explore various attitudes and beliefs [20], [23], [25], and to communicate research findings and disrupt norms [19], [21]. In previous engineering education research, vignettes have been used to elicit participant responses and reactions regarding hidden curriculum in engineering by embedding short video vignettes into a survey [23]. In vignette interviews, however, the interviewer may walk the participant through the vignette and ask questions along the way about what the participant thinks of the characters' actions [19]. In our research context, for example, we developed a vignette based on a fictional engineer, Alex, whose engineering firm is commissioned by the local government to design a playground that serves a dual purpose as a raingarden (Appendix A). Parts of the story are read to the participant and then the researcher asks the participant questions about Alex, their decisions, and other vignette characters.

Photo elicitation

Photo elicitation may be defined simply as an interview in which an image is inserted and used as stimulus for discussion [26] and while mainly used in anthropology, this method has been performed in other fields such as nursing [27] and education [28]. Often, the visual stimuli in the interview are photographs, but other images such as art or films may be used as well [29]. Photo elicitation as a technique originated in anthropology when a researcher studying mental health in the mid-20th century found that interviews including photos of housing quality (instead of descriptive text) evoked memories and reduced confusion among participants [26]. This finding is supported by contemporary understanding of cognition: humans evolved to process visual information before verbal (or written) information [30]. Further, images may be more emotionally or psychologically evocative than text or speech [31]. There are limited examples of photo elicitation in engineering education research. Hatten et al. [31] used photo elicitation to investigate cross-disciplinary learning and identity development in education by asking participants to bring photos representing different aspects of their identities (professional, personal, disciplinary, etc.) to an interview where the images facilitated the discussion between the participant and the researcher. Similarly, photovoice has been used by Henderson et al. [32] to explore the identity of sophomore engineering students. Note: photovoice is like photo elicitation in that participants are asked to capture photos/images in response to prompts, however, photovoice is a methodology designed to support participants in documenting, communicating, and reflecting on their experiences. Photo elicitation is not a full methodology, but a qualitative method used to yield rich data and circumvent some of the limitations of traditional interviews.

Concept mapping

A concept map as a research technique aims to visualize how people connect and relate different concepts. Concept maps are hierarchical, and different concept nodes are connected with arrows that explicitly define the relationship(s) between the concepts. For example, a concept map about photo synthesis may have 'the sun' and 'plant life' as two nodes, and the relational arrow from sun to plant may be 'supports', so the concept map reads: 'the sun supports plant life' [33]. Mind maps, in contrast, do not require relationships to be explicitly defined, and are generally a more freeform diagram of ideas, thoughts, experiences, etc. organized around a central concept.

Concept mapping (and mapping in general) has been employed in a variety of different disciplinary contexts and for different purposes. For example, in public health, mind mapping was used for a real-time data analysis of a focus group in which the researcher produced the mind map as the participants spoke and edited the map with their input [34]. In sociological research contexts, concept and mind mapping is often used as an interview technique to support participant recall and use a participant generated artifact to guide the interview, similar to photo elicitation [35], [36]. This use of concept mapping is grounded in the constructivist paradigm- that each person constructs their lived reality subjectively, and concept mapping is an external visualization of that construction [33]. Concept mapping, or mapping more broadly, is well represented in engineering education literature compared to vignettes and photo elicitation. In education and engineering education, concept mapping has been utilized to support learning [37] and assessment [38]. However, some engineering education researchers have used concept mapping for capturing abstract skills or concepts, such as student perceptions of entrepreneurial mindset [39] and professional skills and sociotechnical thinking [40].

Value of Data Generation Methods for Eliciting Complex Belief Sets

Vignettes, photo elicitation, and concept mapping facilitate elicitation of complex belief sets by engaging beliefs at different levels of awareness

Vignettes, photo elicitation, and concept mapping are promising methods for complex belief sets because the indirect yet contextualized nature of each method requires the participant to draw on their own experiences, knowledge, and beliefs, accessing beliefs that are salient as well as beliefs that only appear in self-reported behavior. Direct lines of questioning, as in more traditional qualitative interviews, are limited in capturing only what the participant is able to directly espouse, in other words, which are wholly salient. However, as discussed in the background, our beliefs exist in complex sets, only one aspect of which are our espoused beliefs. Often, our espoused beliefs are aspirational because they relate to our values but do not represent the full complexity of our beliefs, including those which are implicit, which also inform our behavior. Thus, the selected and adapted data generation methods address this limitation by using indirect approaches to situate meaning in a relatable social context (in our research, engineering service learning or working alongside community partners) and allows the participant to initiate sharing of their personal experiences, including espoused beliefs and values and self-reported behavior and interactions with others.

Additionally, the indirect yet contextualized nature of these data generation methods often reveals misalignment between espoused beliefs, decisions, assumptions, and experiences because they are designed to surface beliefs across the spectrum of self-awareness. This provides opportunities for the interviewer and participant to engage in collaborative sensemaking around the complexity of their beliefs. Vignettes achieve this indirect but contextual approach by situating the participant externally to the storyline but also requires them to put themselves in the protagonist's shoes and assume that the protagonist has similar beliefs and norms, which are elicited in the vignette interview [41]. Similarly, both photo elicitation and concept mapping achieve the goal of indirect yet contextualized questioning by focusing on participant generated artifacts rather than asking directly about their beliefs and behavior. Focusing the interview on the participant generated artifacts allows the interviewer and participant to work to surface the complex belief sets by accessing implicit beliefs that appear in the artifacts. Again, interviewer facilitated sensemaking around comparing and contrasting aspirational or espoused beliefs and beliefs that appear indirectly through the artifacts enables the interviewer and participant to collaboratively surface complex belief sets.

Vignettes, photo elicitation, and concept mapping are methods that can be used to minimize communication barriers when studying complex constructs like beliefs

The data generation methods we selected use mediums that mitigate communication barriers by minimizing abstraction and jargon. A common barrier in studying engineering student populations via qualitative interviews is communication – the interviewer must be skilled in asking questions that students are interested in and able to answer in depth. Often, engineering students may respond briefly to interview questions because they are unsure what the interviewer is asking or they are unable to relate the question easily to their own experiences. Alternatively, students may answer the question in depth but what they heard was not what the interviewer meant to ask. Further, students may try and offer answers that they think the interviewer wants to hear, to say what they think might be "correct" in this context because they are more used to test-like interactions. Socially desirable answers limit the collaborative sensemaking between the interviewer and the participant because they shift the interview focus away from the beliefs and experiences of the participant. This is a pitfall in engineering education research because many research constructs (including beliefs) are abstract and theoretical, and thus the interviewer must take care to interview students with language that is engaging, relatable, and accessible for engineering students. To elicit complex belief sets, the role of the interviewer is to facilitate collaborative exploration and reflection of beliefs and assumptions, which is only possible if there is mutual communication between the interviewer and the participant.

For example, in photo elicitation, photos as an interview medium effectively circumvent complex language because the line of questioning during the interview is based on visual media. With the rise of smart phones and social media, photos have rapidly become a ubiquitous medium in day-to-day communication, particularly for younger generations, such as most of the current undergraduate student population. Thus, using photos as the basis for the interview can support engineering students' meaning making by relating the interview questions to a visual anchor from their context, allowing them to draw on their experiences more deeply and limit confusion due to jargon and abstraction. Further, Harper [26] names encouraging participants to see themselves and their community from different points of view via photo elicitation "breaking the frame" (in contrast to direct questions), and notes that interviews where participants provided photos yielded richer data than researcher provided images of common viewpoints. Similarly, vignettes and photo elicitation both use mediums which support communication by grounding the interview in familiar and accessible language, either from participant generated maps or from the vignette storyline.

<u>Insights for adapting data generation methods within engineering education contexts</u>

Our experiences adapting these three data generation methods for our research purposes have generated methodological insights, which we share in this section. Specifically, we offer three central considerations for others interested in designing and implementing research on complex belief sets in the context of engineering: 1) the importance of leveraging a conceptual framework, 2) the need to minimize fatigue and support engagement, and 3) the need to prepare for implausibility concerns as a barrier to eliciting beliefs.

Align methods within a conceptual framework to elicit beliefs related to the research goals

It is important to leverage a framework when adapting the data generation methods for a given research context because grounding method development in a conceptual framework enables operationalizing the complex belief sets the methods are designed to elicit. In our research context, to ensure that our methods were designed to elicit beliefs related to the relative value of diverse perspectives in engineering, we grounded our method development in our conceptual framework of Robbins' [6] view of reflexive engineering and sociotechnical dualism. For example, to develop our vignette, we decided to anchor the decisions the vignette protagonist made to touch on the different aspects of reflexive vs traditional engineers [6]. Having the protagonist make decisions across the spectrum of traditional to reflexive engineering created more space for tensions and contradictions to emerge in the pilot vignette interviews, leading to rich conversation about assumptions and behavior / values / beliefs alignment. Similarly, the photo elicitation and concept mapping prompts and interview questions were informed by our conceptual framework to elicit complex beliefs specifically about the relative value of diverse perspectives. For photo elicitation interviews, participants are prompted to bring up to four photos or images that illustrate how they worked alongside community partners during their service-learning project, and the concept mapping starting concept is *designing with community*. Interview questions for both methods probed for the relative value of others by asking questions that touched on position and contribution. Thus, centering the research goals, paradigm, and conceptual framework that inform the research design is a critical consideration for adapting these methods to specific research contexts in engineering education.

Further, we aligned method development with the larger research aims that stemmed from our conceptual framework: to enable reflexivity in engineering service-learning students by eliciting complex beliefs sets. Each method was selected and designed to specifically support collaborative exploration of different perspectives, aligned with our research goal of reflexivity about the value of diverse perspectives in engineering. For example, during the vignette, the participant is asked to take on the perspective of different characters by imagining their motives, beliefs, and feelings throughout the story. The use of images in photo elicitation supports exploration of different points of view by encouraging participants to bring in photos from various points of view. Additionally, with some iteration, all three methods have the potential to be conducted without a researcher and translated into a classroom context because they produce artifacts (vignette response, photos, maps) that can support individual reflection.

Format and implement methods to minimize participant and interviewer fatigue and support engagement

The format in which the method is implemented, including length and point of view, should be optimized to minimize participant fatigue and cognitive load and maximize engagement and interest with an engineering student population. As we developed our vignette protocol, we decided to use a written vignette instead of other mediums (e.g. audio or video) because previous literature has reported that written vignettes generally have less cognitive load than visual vignettes [42]. While sometimes it is helpful to ask similar questions from multiple points of view in the vignette interview, we caution against overuse of multiple point of view questioning because the participant can become fatigued by the repetitiveness and their responses may not be different.

Further, the overall method length and process should aim to ameliorate participant fatigue to support rich data. We found that a 60-to-90-minute interview was appropriate for engineering student participants and worked towards that length by iterating the methods through pilot interviews. Interestingly, some photo elicitation literature cautions more against interviewer fatigue than participant fatigue because researchers have found that participants are so excited to share photos or images that are important or interesting to them, they can speak about them at length; one paper cited an interview that lasted over four hours [28]. We have found through pilot photo elicitation interviews that only using one prompt (instead of multiple) and phrasing the number of photos for participants to bring as *up to four* instead of requiring a specific number has been ideal because the interview is focused around one central prompt or idea but there is enough material to provide a rich interview. To mitigate fatigue from repetitiveness, the interview was conducted by discussing the photos as a group, instead of going through the same questions for each individual photo. This led to a more natural conversation that allowed the interviewer and participant to talk about photos individually and how the images collectively created a bigger picture of how the participant engaged with community members during their service-learning experience. These steps are important to minimize participant fatigue, but it is also important to consider the impact on the interviewer. The interviewer's role as a facilitator and collaborator requires them to lead the interview but also meet the participant where they are and then push together towards new understanding without provoking defensiveness. Thus, since these interviews rely on collaborative sensemaking to elicit complex belief sets, the cognitive load on the interviewer is heavy. Minimizing length or having a second interviewer can help mitigate interviewer fatigue.

Prepare engineering student participants for implausibility to center beliefs instead of technical details

Finally, we found preparation for implausibility to be particularly important to elicit complex belief sets with engineering students. By implausibility we mean ambiguous circumstances, lack of technical detail, and overall doubt that the scenario would occur as written. We found preparation against feelings of implausibility important because students tended to overfocus on technical details instead of drawing from their own experiences, knowledge, and beliefs. We were deliberately vague about the technical aspects of the engineering work in the vignette to guide participants towards drawing from their own experience rather than provided information. Engineering students frequently asked questions about the technical aspects of the vignette (the engineering project) and pilot vignette interviews could quickly become unfocused by the lack of technical information provided. For example, participants would say phrases like "I can't be sure, I would need more information" which inhibits expression of beliefs. We were able to refocus the interview and prevent lines of technical questioning from the students by being upfront and candid about how we wrote the vignette. We introduced the vignette by explaining:

> (1) Everything in the vignette is hypothetical, but we (the research team) wrote it by considering what we know about how engineers interact with the communities they design with from previous research; (2) Some of the events and characters in the vignette may seem unrealistic to you but try and continue thinking about the scenario as though it is real; and (3) We intentionally wrote the vignette to be vague and not have all the information, so do your best to answer the questions even if you feel like you don't know enough about it, and feel free to draw on your own experiences to answer the questions.

With this preface, we were able to redirect participants away from seeking technical information and instead encourage them to draw on their beliefs, knowledge, and experience in their response. In photo elicitation, overfocus on technical aspects manifested as participants bringing images with no people in them, but rather, of the physical device they worked on as a part of their project. While this is not an explicitly undesirable outcome, the interviewer should be prepared to redirect the participant away from overexplaining the technical details of their project and instead focus the conversation on the relevant research question, in our context, this could be how the device was developed (or not) in collaboration with community partners, or to ask the participant why the images are not of people but of devices, etc. Over emphasis on technical details was not as big of an issue in concept mapping pilots because of the three methods, this is the most abstract, and the spatially directed nature of the questions focused on what was absent in addition to what was present. Thus, if only technical considerations are mapped by the participant, there is a natural way to refocus the interview by asking them what is missing, where are the contributions of different groups, etc.

Conclusion

In this methods paper we provided background on the benefits of using vignettes, photo elicitation, and concept mapping as data generation methods to elicit complex belief sets. Additionally, we shared three key considerations for implementing these methods based on our experience: 1) the importance of leveraging a conceptual framework, 2) the need to minimize fatigue and support engagement, and 3) the need to prepare for implausibility concerns as a barrier to eliciting beliefs.

Advancing methods in engineering education to elicit complex belief sets is important because our beliefs inform how we make sense of and move through the world. Beyond studying beliefs in research contexts, the major goal of our work is to translate our methods into classroom contexts to enable individual reflexivity. By supporting engineering service-learning students in practicing reflexivity regarding the value of diverse perspectives, we ultimately aim to empower the next generation of engineers in pursuing and practicing equitable and values-based engineering. Identifying patterns of implicit beliefs amongst students will also inform system-level changes that can be directed at shifting culture towards egalitarian approaches being taught within undergraduate engineering education.

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Note on method protocols

We attached the protocols for the methods described above because providing examples can minimize the barriers to adopt and use these methods for the first time. However, note that these protocols are a base for semi-structured interviews. Each interview we conducted was consistent in the base activity (vignette, photo elicitation, or concept map) but there was lots of variation in the follow up questions and sensemaking conversations based on the participant. These protocols are a starting point, but to elicit complex belief sets it is important for the interviewer to be prepared to adapt to the participant and make in the moment decisions about which parts of the protocol to skip or adjust to follow promising lines of thought and conversation.

Appendix A: Vignette interview protocol (including full vignette text)

Vignette introduction and logistics

1. So during our time together today, I'll start by asking you a couple general questions about yourself, and then we'll go through a scenario, and then at the end I'll share a little bit more about the research project and ask you what you think about it.
2. For the scenario part of this interview, I'll be reading you a scenario about a fictional engineer named Alex. I'll read a part of the scenario and then ask you some questions about it.
3. I will be showing you the scenario text so you can refer to it if you need to.
4. Everything in the scenario is hypothetical, but we (the research team) wrote it by considering what we know about how engineers interact with the communities they design with from previous research.
5. Some of the events and characters in the scenario may seem unrealistic to you but try and continue thinking about the scenario as though it is real.
6. We intentionally wrote the scenario to be vague and not have all the information, so do your best to answer the questions even if you feel like you don't know enough about it, and feel free to draw on your own experiences to answer the questions.
7. Do you have any questions about the scenario part of the interview?

Context and background

1. So, I saw from the survey that you are a [year] in [major]. Tell me a little more about who you are and what you're involved in.

2. *Optional:* You shared that you took the service-learning class with [fill in professor] and traveled to [fill in partner location]. Tell me a little bit about your participation in service-learning.
3. *Optional:* How does service-learning fit into your decision to pursue engineering?

The Playground Vignette

1. *Alex is 27 years old and works as an engineer in a large engineering firm. Alex graduated from a large public university in the United States after four years with a B.S. in Civil Engineering. Alex was active during their undergrad. They often pursued student organizations that included community outreach activities to enhance their real-world engineering skills. One of Alex's most memorable experiences was participating in a yearlong service-learning course where they completed an engineering project with their classmates in an international setting.*
2. *Recently, Alex was promoted to a senior project engineer for demonstrating strong work ethic and engineering expertise on their last project. Alex has been assigned to lead a team of engineers on a new project. Their firm has been contracted by the local government to build a public playground that serves a dual purpose as a rain garden, infrastructure to help absorb rain runoff. The playground location will be in a low-income neighborhood where flooding and damage have been on the rise, exacerbated by ongoing systemic challenges resulting from climate change and inadequate infrastructure.*
3. *Alex has identified a primary list of stakeholders for the project: the council members from local government who spearheaded the grant application, a construction company the city works with who will end up building the playground, a representative from the city planning office, and a neighborhood community organizer.*

4. What do you think Alex's first decision to start the project will be?
    - **a.** Probe with repeated 'why' questions
    - **b.** What assumptions is Alex making by starting the project that way?

5. *Alex decides to perform a site visit with their team to the project location. They decide to hold a town hall event and invite members of the community to deliver a presentation on the project scope and plans. Alex also invites representatives from the construction company and local government members to serve on a Q&A panel at the end of the event.*

6. Consider all the different people present at this town hall: Alex and the engineering team, local government and construction company representatives, community members who are presenting, and the community member audience. What are their roles? What are each of them contributing?
    - ***a.*** Is there anyone who doesn't need to be there or anyone who should be there?
7. What are the pros and cons of having community members take the lead on the presentation?

8. *During the Q&A panel, several community members raised concerns regarding the potential impact of the project on their taxes. Additionally, they expressed worry about traffic congestion and noise disturbances resulting from the construction, which could disrupt their day-to-day activities.*

9. Who from the panel addresses (or…would be qualified to address) the concerns the community members expressed?
    - **a.** How do you think they (panel members that respond) would respond? Why?

10. *The government representative and the construction worker decided to respond to the citizen concerns. The government official explained that the project was being funded through a grant so the community shouldn't be concerned about the project cost. The construction firm representative was apologetic and said that due to budgetary constraints and staffing, the length of construction time would require some disruption to traffic flow and noise levels.*
11. *Alex decides to follow up and validate the community members' concerns, adding that it might be possible to adjust the construction schedule once a final design is confirmed.*

12. Why did Alex respond the way they did? Do you think Alex should have said something?
    a. Probe with repeated 'why' questions
    b. Should Alex have done something different?
    c. How would you react if you were an engineer in that situation?
    d. Were you ever in a situation where a community member expressed concerns? What happened?
        i. Probe for values – behavior alignment
        ii. What did you prioritize and why did you do that? What do you wish would have happened and why?
            1. Reality vs idealized goal
        iii. Probe for the relative value of each in that partnership

13. *Following the site visit and town hall event, Alex decides to setup up a design meeting to brainstorm ideas on how to move forward with the project.*

14. Who do you think Alex will invite to the design meeting?
    a. What do you think Alex is hoping they will contribute?
    b. What do you think they will contribute?
    c. Is anyone missing from this list?

15. *Alex ends up inviting the council members from local government, the construction company representative, a representative from the city planning office, and an organizer from the community. The meeting begins with Alex's team of engineers presenting several design ideas for the rain garden playground. The neighborhood community organizer introduces themselves as a person who has lived in the neighborhood for several years and runs a local store. They bring up a concern they have about the rain garden water capacity and offer a possible solution.*
16. *An engineer on Alex's team responds and says that the community does not need to be concerned because the team has developed a predictive model that will measure the effectiveness of each design and then moves on to the next part of the presentation.*

17. What is Alex thinking during the interaction between the community member and the engineer on their team?
    a. Why is Alex thinking that?
    b. How would you have responded to the community member as an engineer on the project?
        i. What assumptions are you making about the community member's knowledge and expertise?
    c. Have you experienced any moments where a community member offered a technical opinion on a design or project? What happened?
        i. Probe for how they engaged the community members and their knowledge

18. *At the end of the design meeting, the stakeholders believed it would be a good idea to bring the design ideas to the community and solicit their feedback. Alex and the team planned a day to visit the community and go door-to-door to ask community members if they could provide feedback on current design ideas.*

19. If you lived in the community and Alex and their engineering team knocked on your door, what would be important for you to see in the designs? Why?
20. What type of feedback do you think the community will provide Alex and the engineering team? Why?
    a. Probe about assumptions if differences between the two answers

21. *As Alex and their team collected feedback, they began to recognize a common pattern amongst responses. Most community members were concerned about the aesthetics of the rain garden design. Only one community member was concerned about technical aspects of the design, such as how the water that is being rerouted by the rain garden will impact surrounding land.*

22. Is that what you expected from the community feedback? Why?
23. Have you done any community surveying? What type of information were you seeking out? Why?

24. *Following the community surveying, Alex and their team generated three final prototype designs for the playground rain garden based on their research and testing.*

25. How should Alex approach selecting a final design?
    a. Probe about people in this process- are the engineers the people deciding? Who is there to give input and feedback and who has decision making power?

26. *Alex decides to hold another meeting with the stakeholder representatives. Alex and their team present the top three designs, which are all technically feasible but vary in drainage design, soil type and aesthetic.*

27. How do you propose the process for narrowing the designs down should proceed? Why?
28. Who do you think should have the final say in the design? Why? Who should not have final say?

29. *Through discussions and reviewing the pros and cons of each design, the council member emphasized the need to remain in budget so the final design that was selected was the design that cost the least amount in terms of materials and construction.*
30. *The stakeholders and the engineering team worked to include concepts different stakeholders liked from all three designs into the final design while staying within budget. However, all stakeholders left the meeting feeling unsatisfied with its outcome.*

31. If you were one of the engineers on the team, what would you discuss with your peers as you left the meeting? Why?
32. Do you think the council member deserved the final say? Why or why not?
33. Have you had any experiences where you needed to balance conflicting opinions in an engineering design? How have you handled that?

34. *The final design was installed at the site location in the community. Over time, the local council members and the community representative notice that the community regularly uses the park however, the use of the space begins to limit the effectiveness of rain garden infrastructure, leading to the return of some flooding in neighboring lawns.*

35. What is your reaction to hearing that the rain garden is not working? Why?
36. Is anyone at fault for the flooding? Why?

37. *Alex is called into a meeting with their manager and is asked about why the rain garden system is not working as intended.*

38. How do you think Alex will explain the situation to their manager? Why?
39. How would you explain the situation? Why?
40. What would you think are the next steps that Alex should take? What would you need to achieve these steps?

<u>Appendix B: Photo elicitation interview protocol</u>

Prompt sent before interview to participant via email

As a research team, we are working to understand how engineering students who have participated in service-learning think about the perspectives of both engineers and non-engineers. For our interview, we are asking you to bring up to four photos to the interview- these can be pictures you took, made, or found (on the internet or elsewhere) that correspond to this prompt:

What images illustrate how you worked alongside community partners during your SL project?

In particular, we really want to explore moments where something was unexpected, or you weren't sure what to do, any moments that gave you pause.

Photo elicitation introduction and logistics

1. Thank you for spending time gathering photos for the research interview today. My hope is that as we talk about the photos together, we can explore your ideas more deeply than in a traditional interview.
2. So during our time together today, I'll start by asking you a couple general questions about yourself, and then I'll ask you to explain your photos, and then at the end I'll share a little bit more about the research project and ask you what you think about it.
3. Do you have any questions?

Context/Background

4. So, I saw from the survey that you are a [year] in [major]. Tell me a little more about who you are and what you're involved in.
5. *Optional:* You shared that you took the service-learning class with [fill in professor] and traveled to [fill in partner location]. Tell me a little bit about your participation in service-learning.
6. *Optional:* How does service-learning fit into your decision to pursue engineering?

Photo Elicitation

7. The prompt for these photos was: *What images illustrate how you worked alongside community partners during the SL project?* and in particular, I really want us to dig into moments that were unexpected or where you weren't sure what to do, or that gave you pause.
8. Tell me about where this photo is from and why you chose this photo.
    a. Follow up Qs: What is this, who is this, what's happening here, what is this person doing, etc.
9. Think about why you chose this photo. What were you thinking about? What do you feel when you look at the photo?
    a. What about this photo is most important to you?
10. What is happening outside of the photo?
    a. Where are your peers / engineers in this image / context? What are they doing?
    b. Where's the community? What are they doing?
11. What activities did you do with the community?
    a. How did they engage or include you? How did you engage or include them?
    b. Why did/didn't the community help with technical tasks?
    c. What was the community member doing when you were doing [technical activity]?
    d. Did the community do [technical task]? Why or why not? Were they given the opportunity?
12. What are the contributions of engineers / community and what value do they bring?
    a. What contributions are theoretically possible for the community to make?
    b. You mentioned they were an expert when it came to X, were there other instances where the community member added value?
    c. What assumptions were you making about community expertise / contribution?
13. What did you expect? What didn't align with your expectations?

Appendix C: Concept mapping interview protocol

Concept mapping introduction and logistics

1. So during our time together today, I'll start by asking you a couple general questions about yourself, and then walk you through a few different mapping exercises and a reflection, and then at the end I'll share a little bit more about the research project and ask you what you think about it.

Context/Background

2. So, I saw from the survey that you are a [year] in [major]. Tell me a little more about who you are and what you're involved in.
3. *Optional:* You shared that you took the service-learning class with [fill in professor] and traveled to [fill in partner location]. Tell me a little bit about your participation in service-learning.
4. *Optional:* How does service-learning fit into your decision to pursue engineering?

Mind map

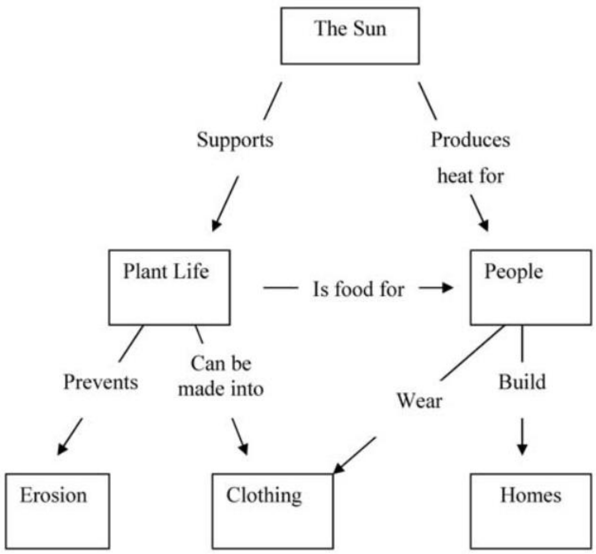
5. [Mind map intro] A mind map is a way to organize and brainstorm your thoughts by writing down ideas around a central concept. Those ideas can connect to each other or lead to new ideas, but they don't have to. Here are a few examples of mind maps *(attached below)*.

6. Do you have any questions about mind maps?
7. As an engineering student who engages with communities through service learning, I'm curious about how you approach working with a community.
8. Please make a mind map with "designing with community" at the center. Try and jot down everything that comes to mind, there are no right or wrong answers. You'll have 5 minutes but let me know if you're done earlier.
9. As we talk, please keep adding to or changing your map if anything else comes up for you.
10. Talk me through your map and how you drew your map.
11. Can you tell me more about this area / bubble / link / etc?
12. Where are the engineers on this map? Where are the community members?
13. What contributions are different people making?
14. [Ask about any obviously missing areas, or spatial layout/categorization ex: no community members on the map, part of the engineering design cycle missing, etc.]
15. [Follow up with lots of why questions]

Concept map

16. [Concept map intro] A concept map is like a mind map in that both relate different ideas to a central concept. The difference from a mind map is that a concept map explicitly shows how different concepts are related to each other. So for example, each line between different concepts states how those two concepts are related. Here are some examples of concept maps *(attached below)*.
17. Do you have any questions about concept maps?
18. Please draw a concept map that explains the process of designing with community, in other words, that shows *how* designing with community happens. The center should still be "designing with community". Pull from your mind map to start but feel free to include new concepts. You'll have 10 minutes but let me know if you're done earlier.
19. As we talk, please feel free to keep adding to or changing your map if anything else comes up for you.
20. Talk me through your map and how you drew your map.
21. Can you tell me more about this area / bubble / link / etc?
22. Where are the engineers on this map? Where are the community members?
23. What contributions are different people making?
24. What assumptions are being made about the role of the community member? About the role of the engineer?
    a. Why couldn't the community member do [technical task]?
    b. Did you need the community member? Did they need you?
25. It seems like X is an important value for you, where and how is that value expressed on this concept map? Where is that value not expressed on the map? Why?
26. [Ask about any obviously missing areas, ex: no community members on the map, part of the engineering design cycle missing, etc.]
27. [Follow up with lots of why questions]
28. [Probe about assumptions, relationships, and contributions]

Concept map example [33]:



Mind map example [43]: