Conversation and Participation Architectures: Practices for Creating Dialogic Spaces with Engineering Students

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Abstract

This paper explores several conversation and participation architectures with affordances for holding challenging and awkward conversations: Open Sentences, Four Voices, Step-back Consulting, and Circle Way. For each architecture, we explore the origins of the technique, which range from the performing arts to spiritual practices to cultural wisdom traditions to medical school pedagogy. We then illustrate how to practice that technique in an engineering education context, highlighting the adaptations and framings we use to make it legible to a technical audience. We also discuss how each architecture is connected to various educational, psychological, and social theories that make-visible how it benefits engineering students. These architectures are compatible with a wide range of course and informal learning settings. They are focused on engaging in, observing, and reflecting-in-action on individual and group dynamics, especially in conversations that challenge personal views and comfort zones. After attending to each architecture in turn, we discuss the collection of architectures as a toolset for facilitating the development of interpersonal skills in engineering students.

Introduction

The ability to engage with and facilitate conversations on complex topics is a crucial skill for engineering students preparing to thoughtfully encounter a world full of diversity, challenge assumptions, and work across disciplinary and cultural boundaries. This kind of communication involves more than simply getting one's own points across clearly; it also requires the ability to empathically listen and create spaces that foster honesty. This paper explores four conversation and participation architectures that provide engineering education students and practitioners with affordances for holding challenging and awkward conversations.

Conversation and collaboration skills are an important facet of engineering student development. ABET student outcomes criteria (d) and (g) emphasize the ability to function on multidisciplinary teams and the ability to communicate effectively, respectively [1]. We argue that, in an increasingly complex and transdisciplinary world full of "wicked problems" [2], engineering students need to develop a high level of these skills. It is not enough to know and follow simple, algorithmic rules for clear interactions; engineers must be able to create and navigate nuanced, subtle spaces, emotionally volatile topics, and areas filled with complexity and tension.

More recent work in higher education has examined the use of contemplative practices and indigenous dialogue formats as tools for enabling difficult conversations in a variety of disciplines [3, 4, 5]. In fields such as counseling, teaching, and pastoral care, these skills are developed through hands-on clinical practice rather than as abstracted concepts. Dall'Alba describes this as an ontological approach to the development of professionals – that is, developing their ways of being professionals – rather than simply developing their stores of knowledge about their profession [6, 7]. We bring this discussion into the context of engineering

education by showing how contemplative dialogic processes can impact the formation of engineering students.

Undergraduate engineering education often involves hands-on and team projects, but discerning when and how to critically reflect on conversational skill development can be a challenge. We present conversation architectures as potential solutions that complement existing practices and approaches in engineering education. Conversation architectures are our umbrella term for communication and participation structures designed to scaffold the creation of reflective space where students can focus on metacognition and communicative skill development, while still discussing their engineering learning activities in context.

Paper Structure

In this paper, we present four conversation architectures: Open Sentences, Four Voices, Step-Back Consulting, and Circle Way. There are many more conversation architectures we could explore, but we choose these four as a starting point because of their clarity, their existing usage in engineering education settings, and the ways in which they directly challenge ways in which engineering students are socialized. They are ordered from simplest to most complex in the sections that follow. All four architectures are compatible with a wide range of course and informal learning settings; they are focused on engaging in, observing, and reflecting-in-action on individual and group dynamics, especially in conversations that challenge personal views and comfort zones.

For each architecture, we describe its origins outside of engineering education, then paint a brief sketch of what the architecture looks like in action within an engineering education context. This paper does not intend to be a full instruction of how to practice each architecture; instead, our references point to resources where interested readers can learn more. After briefly sketching each architecture in the engineering education space, we discuss how that architecture relates to elements of current engineering socialization, and adaptations that might be particularly pertinent to the engineering education space. After describing the four architectures, we discuss the ways in which such architectures can be used more generally for facilitating the development of interpersonal skills in engineering students.

Architecture: Open Sentences

What it looks like

Open Sentences is an architecture designed for expansive exploration of a topic in a short period of time. Our work with Open Sentences in engineering education is based on the workshops and books of systems scholar and eco-philosopher Joanna Macy, who explores how people respond to challenging environmental and social constructs [8, 9]. Macy's book, *Coming Back to Life*, provides more detailed instructions on how to facilitate this conversation architecture [8]. Less formal variants of this architecture are also sometimes used in situations where feedback is being collected, such as the constructive criticism technique "I like… / I wish…" described by Tom and David Kelley in their book, *Creative Confidence* [10].

The Open Sentences architecture involves a facilitator and a group of students that has been organized into pairs (person A and person B). The facilitator provides the opening to a sentence. A good open sentence fits these criteria: it is in the first person (an "I" sentence), it has many possible completions, and it prompts personal reflection. To offer a real-life example from a first-year engineering course centered on biomimetic design, an instructor might prepare students for a new project with prompts such as "I am excited about learning…" or "When I look at the biomechanical systems that animals use to jump, I wonder...".

Each pair chooses who will speak first and who will listen first. The speaker begins by repeating the open sentence and completing it, then continues talking. Every time the speaker feels stuck about what to say next, they return to the open sentence. For instance, a student with limited machining experience who chose to pursue engineering in order to work on sustainability technologies might respond:

- <u>I am excited about learning</u> about animals and how animals move; I think there is so much we don't understand in terms of creatures and ecosystems, so developing a sense of humility and being able to look for inspiration in all kinds of places is great.
- <u>I am excited about learning</u> how to work on a team, and how to come up with ideas and make them happen.
- <u>I am excited about learning</u> how to build things, not just functionally making them, but actually developing a sense of craftsmanship about how to build things well…

While the speaker is talking, their partner is actively listening. They do not comment, interrupt, or judge; they simply pay attention. This allows the speaker to proceed without the expectation that the other person will respond or critique. After some time, the speaker will feel like they have run out of ideas; this will appear as a pause, and may feel uncomfortable. The listening partner continues to actively listen. This forces the speaker to continue past their first surface associations and push into deeper levels of connection and ideation that may not be immediately obvious. The speaker continues to work on generating additional completions for the sentence until the facilitator calls for time.

The facilitator's job is to monitor when speakers in the room have paused not only once, but several times. The speaking time should feel longer than is comfortable; speakers should be visibly searching for additional answers after they have shared the first thoughts that come to mind. This typically takes at least 2-3 minutes, but can take longer for a more talkative group. Once most speakers have paused several times, the facilitator calls out that the first speaker's time has ended, and the roles switch; the speaker becomes the active listener, the active listener becomes the new speaker, and the process repeats.

Responses to open sentences provide opportunities for students to notice and appreciate a diversity of approaches to the same topic. The student above starts by discussing animals and ecosystems in ways that might relate to their interest in sustainability. Their partner, who wants to prove technical competence and get a summer job, might respond differently:

- <u>I am excited about learning</u> more advanced machining, because I ran out of machines to learn about in my high school shop; I was good at machining, and want to offer my fabrication skills to my team.
- <u>I am excited about learning</u> CAD, because that's a software tool I haven't used before, and it might help me get a summer job. If I do, maybe I can buy my own flight home for Christmas and save my parents some money.
- <u>I am excited about learning</u> how project management works, because I had some really disorganized teams in high school and want to do better...

The two student examples above are truncated; in the actual activity, each would continue to speak for several minutes, often with pauses and hesitations. Nevertheless, the differences in approach are apparent (sustainability, teamwork, future-oriented, new to machining vs. experience, career-oriented, reflecting on high school experiences, etc.). The combination of the Open Sentence and the open time for each person to speak without interruption allows for spontaneous, frank, and multiple responses.

Challenges and adaptations in the context of engineering socialization

The Open Sentence architecture encourages the development of divergent thinking, which is essential in activities such as brainstorming that are often used in engineering design courses [11]. Defining the activity by time rather than by completion of a task results in the challenge of coming up with more ideas than those that are most obvious. The addition of having someone actively listening, without responding, encourages the person sharing to not filter their thoughts or ideas. Similarly, creative professionals emphasize ideation guidelines such as "defer judgment" to encourage the free flow of ideas that might lead to surprising discoveries [10, 12].

The cultural valuing of objectivity by STEM fields has been questioned by science and technology scholars pointing out the inevitably subjective and humanistic nature of knowledge pursuits [13, 14]. In our experience, engineering culture tends to value objectivity, neutrality, and measuring skills by a "standard" metric that applies to all. However, engineering education also values several competencies that can be at odds with such a culture. For example, ABET recognizes teaming as an important skill for engineers to develop, and diversity as an element we wish to increase in our field [1]. Additionally, teaming and diversity rely on and benefit from the inclusion of intersubjectivity (multiple interacting points of view) alongside discussions of "objectivity." Integrating conversation architectures that value and develop intersubjective statements allows multiple perspectives to come out so teams can take advantage of them in their work. Open Sentences also allow students to share their personal interests and values; connecting with these inner interests can increase their intrinsic motivation [15].

Open Sentences can lead to emotionally vulnerable spaces when students share their values, motivations, and fears. In our experiences, engineering curricula do not typically provide many spaces for the development of affective skills, and facilitators should keep this in mind. For instance, it may be helpful to use a progression of Open Sentences that gradually increases the level of vulnerability required so as to ease students from a context where personal affective experience is uncommon. Begin with low-risk Open Sentences that allow for various levels of comfort. To take a real-world example from a sustainable design class exploring the design of

environments, beginning with an Open Sentence such as, "A place that I loved as a child…" is safer than "When I look at the world today, what I find most heartbreaking is…" Along similar notes, beginning a feedback session with an Open Sentence that prompts positive feedback is often easier for students, and cultivates greater openness to then progress to sharing critical feedback, such as, "When I reflect upon my experience working on this team, I wish…"

In the engineering education context, the Open Sentences architecture can be applied and adapted in several ways. In each case, the purpose of the Open Sentences exercise should be directly reflected in the specific phrasing of the Open Sentence. For example, if the intention is for students to provide feedback to their team members for a project, a good Open Sentence would be, "When I reflect upon my experience working with this team, I liked…" This phrasing emphasizes the student's personal experience and encourages feedback that is more likely to be generative for team members. In contrast, an Open Sentence such as "What our team did well is…" is more likely to solicit answers that the student believes are correct, rather than their actual experience of teamwork.

Architecture: Four Voices

What it looks like

The Four Voices architecture engages people's imaginations in order to explore multiple perspectives on a particular issue. It is oriented towards developing the skill of articulating your own perspectives while respecting and becoming more curious about other points of view. The particular version we discuss here is described in Joanna Macy's book *Coming Back To Life*, where she also names it "Widening Circles" [8]. A similar framework sometimes used in management training is Edward de Bono's Six Thinking Hats, which instructs users to put on the perspectives of six different "hats" when considering a problem [16].

The Four Voices architecture does not require a dedicated non-participating facilitator; so long as everyone is clear on the process, all can participate. Participants split into groups of 3-4. Each person in the group takes a turn at being the speaker while the others practice active listening. When it is a speaker's turn, they choose an issue of importance to them and speak about it from a number of different voices. In Joanna Macy's work, the following four voices are used:

- your own
- that of someone who holds an opposing view
- that of a non-human being affected by the issue
- that of a future human whose life is affected by the issue and decisions being made.

The speaker progresses through each voice in turn, using first person ("I") statements and imagining being in that person's place. Another person in the group watches the time, allowing 2-3 minutes for each voice, indicating when the speaker should transition to the next voice, and encouraging a moment of silence between voices. The (shortened) example below comes from an engineer discussing the topic of fossil fuels:

- Speaking as themselves: As an engineer, I am concerned about the present and future implications of using fossil fuel energy. I feel that we need to, as a community, take a very strong stand on what energy technologies we develop...
- Opposing view, speaking in the voice of an engineer in the fossil fuel industry: I have invested my entire career in becoming an expert in fossil fuels, and I pride myself in trying to make these technologies more efficient. As long as there is demand for fossil fuel energy, I am going to be invested in making sure this industry stays alive...
- Non-human, speaking in the voice of a river fish in a mountaintop coal mining area: I'm worried – I don't know how much longer my descendants or I will survive. More and more of us are dying because humans are dumping toxins into our home, and they don't seem to care. I wish I could tell them to stop, and to show them how much is being lost...
- Future human, speaking in the voice of a general future human: I live a life that is much more challenging than my ancestors. My grandparents brought this land, but I worry that I will have to leave it soon – the last several years, intense droughts have yielded failed crops. I wish that past generations had changed their ways sooner...

After the speaker finishes speaking from the fourth voice, there is a moment's pause as the speaker role shifts to the next person in the group (and the facilitator/timekeeper role also shifts, if needed). No commentary, discussion, or response occurs until all members of the group have had a chance to speak about their chosen topic from all four voices.

Challenges and adaptations in the context of engineering socialization

Engineering courses often train students to optimize a solution based on specifications. These specifications are generally based on "objective" criteria such as facts and figures, which are then applied to converge to a unique correct answer [11]. Emotions are considered biased and unimportant; feelings are supposed to be set aside in order to pursue the "right" answer. This architecture disrupts the assumption that there is always a "right" and/or technical answer, which can be an unintentional result of engineering courses focused on getting the "right answer" to homework problems. Instead, it highlights the insights that can arise from engaging with experience as a whole.

Our intent is not to dismiss facts and figures and rigorous proof from engineering practice; such things are extremely important. They do not, however, capture the entirety of our experiences as human beings. Feelings and facts are not the same thing, but it is a fact that people have feelings and that those feelings influence their thoughts, beliefs, and actions [17]. In engineering, we often devalue the affective aspects of these discussions, and sometimes forget to bring up the moral/ethical aspects of our positions. This architecture develops the moral imagination of engineering students by examining how their actions impact others.

The ability to make meaning of complex, open-ended problems is critical to the success of professional engineers in the workplace [18] and has been examined as a specific difficulty that engineering students have [19]. The Four Voices architecture provides an alternative to simply "finding the best solution" to the issue being discussed. Instead, it asks participants to consider how and why different parties might have conflicting views of what the "best" outcome might mean. This architecture is about expanding our perspectives and cultivating curiosity about the

perspectives of others. At a basic level, simply making students aware of the existence of other perspectives as legitimate (rather than "wrong") is a crucial step.

The Four Voices architecture can be useful in interdisciplinary classes, where students from different majors can bring their disciplines to bear on the same topic. It can also be applied within technical classes that want to contextualize technology's impact on society and/or the environment, as well as in engineering ethics courses and conversations. In each case, the number and type of voices should be matched to the issue.

For example, the non-human being is included in Macy's Four Voices because the practice was developed in the context of environmental issues; however, it might not be as relevant in other contexts. The voices should represent a range of perspectives that include diverse stakeholders affected by the issue in different and conflicting ways. In particular, the "non-human" voice could come from the technologies the engineering students are studying or creating. For instance, one engineer in a meeting chose to spoke from the point of view of a piece of medical equipment she was frequently embroiled in design debates about; the device spoke about how it felt to be developed so rapidly and used so widely.

Adaptation of the Four Voices architecture to the specific engineering education environment it is being used in can also be an exercise in and of itself for engineering students. Facilitators can create and supply the voices to be used, or they can include the identification of stakeholders as a pre-step to the activity. To draw on a real-world example, in a class where students design technologies for aging alongside older adults, students could be prompted to generate a list of distinct voices relevant to design for aging (e.g. an engineering student trying to design technologies for aging, an older adult with age-related disabilities, a family member who acts as the primary caretaker of an older adult, the same older adult in the future using a designed technology for aging). The task of brainstorming the list of diverse voices, in and of itself, can prompt greater awareness of personal biases and assumptions.

Finally, it is important to note to engineering students that, while the Four Voices architecture gets them to consider alternative points of view, this is not the same thing as knowing those alternative points of view. For instance, a young student speaking from the "voice" of an elderly factory worker is voicing their conception of what that person might say, not what that person might actually say if they were in the room. When used with this caveat, the architecture develops cognitive and affective empathy, which have been shown to decrease discrimination, increase emotional intelligence, and yield actions that better address people's needs and values [20]. In an engineering context, facilitators can frame students' "voicings" as hypotheses of what alternate perspectives might sound like, and use this to examine personal biases and spur student curiosity about going out to meet real people who can speak from those perspectives in order to see how their hypotheses might hold up. In developing greater empathy for the perspectives of others, students also become more aware of what values, biases, and assumptions shape their own experiences and beliefs.

Architecture: Step-Back Consulting

What it looks like

The Step-back Consulting architecture was developed by Robert Kegan at the Harvard Macy Institute and has been used for facilitating critical conversations in medical education. A more detailed version of the protocol is available online [21]. It has also been used for several years in an engineering education context, including at a Frontiers In Education (FIE) workshop on curricular change impact [22] and at Olin College's Summer Institute program, where groups of faculty working on curricular change projects use the architecture to help them think about their projects differently.

The architecture is designed for participants who are working on a specific project and wish to get feedback on that project. It is a time-intensive architecture; the original version takes approximately three hours to run in full. So long as all parties understand how to use the architecture, a non-participating facilitator is not needed; however, it can be helpful to have a designated facilitator to keep time and remind other participants of the steps of the process. Participants are grouped into trios, where nobody on the trio is on the same project team (i.e. they should be bringing different projects to the discussion, and it is ideal if people do not have familiarity with the other people and projects in their trio). In a trio with members A, B, and C, the process runs as follows.

- Person A has up to 10 minutes to present their project to B and C. During this time, B and C may ask any questions they wish. This time is deliberately kept short so that person A will be unable to "fully explain" their project to B and C; it is important that person A feel unable to clarify everything that is going on.
- Following this, person A "steps back" and becomes a silent observer as B and C take 30-40 minutes to discuss A's project as if A were not in the room. Person A is not allowed to interrupt, respond, or react; they are practicing active listening, and noticing what sorts of reactions they may have internally to the conversation. Person A is allowed to take notes.
- Person A is then allowed 5-10 minutes to respond to B and C's conversation, describing what they heard, how they feel, and what they learned.

At this point, nearly an hour has passed, and trios may want to take a short break. After this, roles rotate, with person B describing their project to A and C, and so forth. Excerpts from an example conversation loosely synthesized from an engineering senior capstone project (details changed) follow:

- Person A: We're falling behind on our capstone project. I really don't think the software platform we're designing is appropriate for the high school students we are supposedly making it for, and want to switch to a more beginner-friendly programming language for them, but we're already two weeks behind and my teammates just want to keep going... (*continues describing the issue, then steps back for B and C to discuss*)
- Person B: It sounds like A feels like she should be working extra hours outside of class to prototype the project in a different language so she can show her team it works.
- Person C: But A doesn't have time to do that. I talked with her roommate last week, and she said A is already not sleeping enough because of being in the play. I don't think it's a good idea for A to get less sleep. (*Person A struggles not to interrupt, fidgets anxiously towards her notebook*)

- Person B: I wonder if she could bring in an actual high school student and ask them to test the software in front of another team member. Then they could prove the current system doesn't work.
- Person C: Yes, and A wouldn't need to build a whole new prototype before doing that; they could do that during a team meeting -- doesn't one of our professors have a high-school kid? They could see if one of their friends wants to come by... (*they continue until it is time for A to respond*)
- Person A: When you said I shouldn't spend more time on this because I was already not sleeping, I definitely got defensive and wanted to interrupt you -- but you're right, I can't just solve a technical problem by putting in more time I don't have. If I'd interrupted you then, I would never have heard your idea about bringing a high school student in; I think they would listen to that, and some of the kids on the local robotics team I coach might actually be willing to help me with it... (*continues until end*)

Challenges and adaptations in the context of engineering socialization

Engineering training for communication tends to be geared towards high-consensus language usage [23], which aims for clarity and disambiguation. Technical writing is a good example of this; there should be one and only one way to interpret a sentence, especially in technical specifications. Misinterpretation is framed as negative. Instead, this architecture works against disambiguation and completeness, emphasizing communication as hermeneutic rather than a matter of straightforward information transmission, and showcasing the advantages that "misinterpretations" can provide [24]. This is the reason the architecture constrains explanation times to 10 minutes or less at the start. If person A keeps going, they will inadvertently get B and C to think about the problem in a similar way as they have conceptualized it, and one of the benefits of "overhearing" others' perspectives is that they may present a new way to conceptualize the reality of the problem space.

The Step-Back architecture can be especially useful in the context of design reviews or idea generation in the context of complex situations/projects. In a classroom setting, it is unlikely that a full three hours will be available to go through the Step-Back cycle as described above. However, this length of time is only needed for large and complex projects such as a senior capstone. Shorter, in-class project work or research work can be done in a shorter amount of time. The step-back architecture can also be done as homework outside of class if students are easily able to meet (easier in a residential rather than commuter campus), or shortened depending on the size and scope of the issue being discussed. We have successfully run step-backs with 2-minute presentations, 10-minute "overhearing/discussion," and 1-minute response sessions, but tight timing is important in these situations.

The Step-Back Consulting architecture also emphasizes the importance of enabling multiple kinds of voices to be heard, including the voices of "non-experts" in a field. The "non-expert" view is useful precisely because it "misinterprets" the situation and produces new views of reality that can lead to generative thinking. Instead of being framed as erroneous, this "miscontextualization" can be used as an aid to think differently. This helps students recognize divergent thinking and multiple perspectives as valuable in revealing new ways of thinking and understanding a situation [11]. "Overhearing" others discuss their presentations reminds students

how their work might be experienced by outsiders, prompting them to think more critically about the ways in which they tend to speak about their work. Do they contextualize their problem statement? Do they dive into levels of technical detail that their listeners cannot follow? In this way, the architecture also develops more advanced communication skills.

Architecture: Circle Way

What it looks like

The Circle Way is a complex and challenging architecture that, more so than the other three architectures, cannot be fully explained in the space constraints we have here. It requires participants to share a goal of collective trust-building, and may be more suitable to longer-term, smaller-scale conversations such as full-semester capstone teams (vs. large lecture courses) and opt-in activities such as clubs (vs. mandatory course assignments). The explanation below gives a partial glimpse into what the Circle Way looks like; for a more in-depth look, see [25].

Circle is an architecture for developing the capacity to collectively "hold a space," where a group is able to consider progressively difficult and possibly volatile topics while paying attention to their individual reactions during a challenging conversation. Baldwin and Linnea's work is based on wisdom traditions, and is currently passed on via an international series of workshops and books by the Calling the Circle Foundation.

Circle architecture takes place, as the name implies, in a circle made of two or more participants. One participant takes the "host" role and places a question or topic in the center of the circle for discussion, along with a physical object that serves as a talking stick. Any participant may begin by taking the talking stick; turn-taking proceeds around the circle from that point thereafter, and participants may opt to pass when the talking stick comes to them. During the discussion, all participants place their ideas and thoughts "in the center of the circle" -- they are not referred to as "Person A's idea" or "Person B's objection," but as things that belong to the group as a whole. Once the talking stick has made it way around the circle and those who have passed are given one more opportunity to speak, a discussion round is over and a new one may begin. The example below is loosely drawn from one author's experiences with a group of instructors discussing the capstone projects they were facilitating.

- Person A (host): The first question I wanted to put on the table was: how did last month's project meetings go? Whoever wants to begin may begin. *(places talking stick in center)*
- Person B: I'll start *(takes talking stick)*. I loved seeing the projects; they're shaping up very well. But I was concerned at how quickly some people are jumping into their projects; do you remember (shares anecdote)? I don't get the sense she's letting herself explore a wider solution space yet, and time is running out so it'll only get harder *(hands talking stick to C)*.
- Person C: I'll pass *(hands talking stick to A)*.
- Person A: Thanks. I do remember that moment, and it reminded me of one project last year... *(tells story)*. That person really needed the last-minute time pressure to force their radical design change, and I think it was transformative for their future work; they're so

much more willing to explore options early on now *(pauses)*. Let's see. Who passed this round? Would you like to speak now? *(Offers talking stick to C)*.

- Person C: *(thinks for a moment)*. Actually, yes *(takes talking stick)*. I wonder how we might build resources to support radical last-minute design changes without encouraging everyone to procrastinate… *(discussion continues)*

Another aspect of Circle Way is attended to by the participant taking the role of "guardian." The guardian watches the group's collective attention: are people getting restless, bored, tired, etc.? If so, the guardian signals (typically with a bell) for the group to collectively pause and take a break together before resetting their attention to the circle. The break may range from few deep breaths together to a more extended coffee/bathroom/walk-around break. Anyone may also signal the guardian for this sort of pause at any time. Pausing the circle need not be a negative thing; the guardian may call for a pause so that the group can appreciate or reflect on a particularly profound comment before continuing. An example is given below, showing a participant calling for a pause to help them re-engage with the group:

- Person B (to person C, who is acting as guardian): Can I call for the bell?
- *(the guardian rings the bell; the group pauses for a moment of silence, then the guardian rings the bell again)*.
- Person B: I called for the bell because I found myself starting to wander; for some reason, I feel like I already know all of this and don't need to listen to my teammates talk, but I don't think that's true. I needed a moment to step back and refocus so I'd be fully present for the discussion.
- Person C: *(nodding)* Actually, I needed that too.
- Person A (host): Thanks for letting us know. Come to think of it, we've been going for a while, so why don't we do one more discussion round and then take a 15-minute break? *(people nod agreement; discussion continues)*.

In an engineering education context, we have used the Circle Way format to facilitate faculty discussions on engineering curriculum design. We have also used it as the discussion format for a graduate-level course on signal processing, where technical topics discussed in the prior week's class were placed in the center for the class to explain, comment on, and ask questions about. The Circle architecture can be used to hold both intellectually and affectively difficult topics; it is just as useful for discussing audio filters as it is for discussing racism in engineering.

Challenges and adaptations in the context of engineering socialization

This architecture challenges engineering cultural conventions that are not conducive to working on complex, interdisciplinary projects. Engineering projects are often approached as systems that can be divided into constituent parts with well-defined relationships. Consequently, interdisciplinary teams can divide a problem into those parts, work on them independently, and deliver their solution as a black box with defined inputs and outputs. This approach does not work for "wicked problems," because a complex system has emergent properties and non-fixed relationships [2, 8]. Instead of framing an engineering problem as being composed of discrete systems, the Circle Way recognizes that the parts are not only interacting, but that the boundaries

between them are shifting, arbitrary, and often far from clear. The Circle Way challenges participants to shift their orientation from a collection of individuals to a co-creating community.

For instance, consider a technical project team: one typical approach would be to break down the project into the electrical, mechanical, and software (etc.) engineering sub-projects, assign each to the student(s) of that major, and integrate the completed parts into the whole system at the very end. If instead students used the Circle Way approach to discuss and share ideas about the whole project, including all aspects of the system, a very different solution and process might emerge. In other words, the role of someone with an electrical engineering background might be to encourage that voice/perspective in the group, rather than being "The Electrical Engineer" and coming up with all the electrical-related ideas for the project.

This architecture also provides a framework that allows for all voices to be heard. For instance, some engineers have a more active (extroverted) learning style and tend to jump into discussions immediately, whereas others have a more reflective (introverted) one and benefit from more processing time [26]. In general, cultural norms bias discussions towards active learning styles, meaning that reflective people have fewer opportunities to participate [27]. By structuring the conversation, the Circle architecture (and the others presented in this paper) give reflective participants more room to breathe and add their voice. The talking stick and ability to pass one's turn also removes the cognitive load of having to figure out how to insert oneself into the conversation, meaning that participants have more cognitive ability to focus on listening. A corollary of this is that silence is typically present and respected as a time for thought, rather than a "useless" space to be filled with talk, which further helps reflection.

Finally, this architecture challenges a lot of engineering student habits and often raises discomfort. In our experiences, to many engineers focused on "efficiency," silences seem "useless." Part of Circle work is explicitly noticing one's own internal reactions to the discussion, and eventually (time and comfort with other participants permitting) bringing them up for discussion in the circle itself. When skillfully facilitated, Circle architecture can help engineering students develop a highly-tuned sense of self-awareness of their habits both individually and as a team.

Discussion and Conclusion

These conversation architectures have the potential to help engineering students develop the communication and collaboration skills they need to effectively contribute to an increasingly complex and transdisciplinary world full of "wicked problems" [2]. We suggest that adding them to classroom and extracurricular contexts can complement existing approaches and pedagogies. Specifically, these architectures can foster a greater awareness of various interacting elements of interpersonal communication, such as social and cultural context, non-verbal as well as verbal elements, and shifting rather than fixed roles and relationships.

Each of these architectures challenges students to simultaneously be aware of their personal experience, the experiences of others, and the interactions between the two. Increasing self-awareness of one's own communication habits allows for opportunities to reflectively shift them. In Step-Back Consulting, for example, hearing how others interpret or "misinterpret" project

descriptions provides valuable information for improving communication clarity and legibility for various audiences. Furthermore, prompting students to not only engage with, but also reflect upon the impact of these architectures allows for an additional level of processing. For instance, after the Four Voices architecture, a student might comment, "This made me realize how much I don't know about these different perspectives and see that it is really important for us to understand the stakeholders before deciding how to progress in this project." After the Circle Way practice, a student might notice, "I'm usually quieter and don't share my thoughts in a big group conversation, but with this way of speaking I didn't have to worry about deciding whether or not to raise my hand, and I was ready to share when it was my turn." Not only do students discover additional insights, but they also develop the ability to articulate and apply these skills to other contexts.

These architectures facilitate divergent inquiry and thinking, which aid in the navigation of complex, open-ended problems. Such problems usually have high levels of ambiguity and uncertainty and benefit from the exploration of multiple different perspectives. In the case of the Open Sentences and Four Voices architectures, participants can become more conscious of the diversity of views and ideas within individuals and groups. In the Step-Back Consulting architecture, participants explore how the framing of projects or problems can impact the solution space that people are able to envision. The Circle Way architecture builds the skills necessary to hold spaces and silences within which alternate perspectives may be raised without immediate judgment. When students learn to both raise divergent perspectives and create environments in which others can do the same, they increase the capacity of our discipline to do this kind of work.

When students become aware of the value of multiple views, they are prompted to develop skills for negotiating those diverse perspectives. In the case of the Four Voices architecture, for example, participants consider how different stakeholders might be impacted by a given situation. Raising this awareness encourages students to empathetically engage with these multiple, and often competing, views and values as they move forward with a project. Students are challenged to consciously engage with questions of engineering ethics while they work on technical solutions. In addition, these practices sensitize participants to how conversation architectures affect which voices are heard. This allows them to intentionally engage and question larger systems of power and privilege. These skills are essential for working on teams, especially when they involve individuals from different cultures, backgrounds, and/or disciplines.

Though we have focused on applications to undergraduate engineering classrooms, we believe that these architectures can be applied to various other contexts in engineering education and practice. These include graduate-level pedagogy, professional work environments, and extracurricular activities. A potential future area of contribution is to develop more detailed lesson plans that integrate these practices into specific engineering courses. These architectures are most beneficial during project phases of exploration and divergence, as well as moments of reflection and feedback. They are less beneficial in situations where the goal is content-delivery or fast decision-making; in these contexts, existing pedagogies may be more advantageous. By exploring how these architectures work both within and against existing communication

practices in engineering education cultures, we collectively develop our capacity to collaborate within complex problem spaces.

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