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ABSTRACT

While project-based learning purportedly values student agency, supporting and managing agency remains challenging. We conducted a design-based research study to explore ways problem authenticity and task and participant structures can contribute to students' framing agency, in which students make decisions that are consequential to their learning through ill-structured problem framing. We compared three semesters of an undergraduate engineering design project (cohort 1 n=70; cohort 2 n=70; cohort 3 n=66), using discourse analysis to investigate how task and participant structures supported participation. Students in the first and third cohorts displayed framing agency, while those in the second used their agency to treat the task as well-structured. We discuss implications for designing ill-structured learning in terms of participant and task structure and problem authenticity.

Keywords: agency, discourse analysis, undergraduate, engineering, design-based research

Introduction

Faculty who teach with projects commonly aim to offer learning experiences in which students make decisions that are consequential to both what and how they learn. However, sustained learning experiences in systems that incentivize efficiency and accuracy can sabotage these aims. This issue is complicated by the means instructors use to make challenging tasks accessible to students. Specifically, scaffolding is a form of structural control that extends what students can do. Yet, scaffolding also limits students in ways that have bearing on their development as decision-makers. These tensions may, in part, explain what Walker and Leary (2009) characterized as a "large amount of variance among the findings" of early medical education problem- and project-based learning (PBL and PjBL) studies.

Rather than focusing on whether PBL and PjBL work, studies have investigated how learning happens in PBL and PjBL. Specifically, task and participant structures shape the

discursive and interactional engagement that unfolds in implementation. This focus leads to more theoretical accounts of the conditions under which learning may be supported via PBL and PjBL (Imafuku & Bridges, 2016; Sandoval, 2014). Such studies have characterized ways PBL and PjBL classrooms differ from traditional forms of instruction. The latter tend to follow a pattern of instructors initiating a question, students offering a reply, and instructors evaluating its accuracy (I-R-E). In contrast, PBL and PjBL classrooms have more varied discourse patterns, some of which are student-initiated and student-driven (Lemke, 1990; McQuade et al., 2020; Mehan, 1985; Polman, 2004). Conversations amongst students as they work on a challenging problem can reveal much about their understanding of the task and their efforts to take collective responsibility for the work (McQuade et al., 2020). For that reason, analysis of such conversations should also shed light on students' agency. However, agency remains undertheorized in PBL and PjBL learning settings. Even when agency is referenced, it is commonly treated as

desirable, but remains undefined (Chan & Blikstein, 2018; Jones et al., 2013; Lee et al., 2014; Marshall & Harron, 2018) or entangled with related ideas of voice and empowerment (Schettino, 2016). Understanding agency in PBL and PjBL classrooms can clarify who and what has power in the learning process and characterize the kinds of experiences needed to reach more expansive learning goals that include not only content acquisition, but also professional skills and identity.

Theoretical framework

To situate our study, we draw together theory about learner agency, and task and participant structures. We define task structure as the sequence and configuration of learning activities, including their characteristics as problems (i.e., authenticity, complexity, structuredness, domain specificity; Jonassen, 2000; Serrano & Pons, 2007; Strobel et al., 2013) and participant structure as dynamic yet recognizable macro and micro interactional patterns that occur as part of learning (Goffman, 1974; Goodwin & Heritage, 1990; Jordan & Henderson, 1995). We argue that authentic design problems offer contexts for students to display and develop framing agency—that is, the capacity to make decisions that are consequential not only to the solution, but also to how they frame the ill-structured problem they are working on. For instance, consider two task structures: (a) Students in a group are given four algal strains to learn about. They each research one strain, then evaluate all the strains according to criteria provided by the instructor, who knows which algal strain should be evaluated as best. (b) A team is tasked with proposing an algal biofuel plant for a rural community of their choosing. To develop their proposal, they choose which algal strains to investigate and come up with the criteria to evaluate the algal strains. In the former task, students' agency is limited, in that their choice is about who will do what work. In the latter task, their agency is consequential because their decision about the community impacts the criteria; their decisions about which algal strains to investigate impact which strains they select from, and in turn, the varied information available in the literature can lead them to reconsider both criteria and strains; and ultimately, these considerations provide opportunities for them to learn about both the content and how to direct their work.

While we view authentic problems as particularly potent for inviting framing agency, such problems are not ready-made for learning. We therefore draw upon research on task and participant structures that scaffold students to engage in generative and agentic learning with such problems. However, while scaffolding enables students to access and work with authentic problems, scaffolding also limits what students may control, a tension we explore. Through this

section, we weave connections to the particular authentic problem with which students in this study worked: economically-viable algal biofuel production for a rural county.

Task structures: Authentic design problems invite agentic learning

The term authenticity has been critiqued in educational research for being vague, as well as for suggesting that educational settings are somehow not legitimate in their own right (Strobel et al., 2013). We adopt Strobel and colleagues' (2013) definition, which anchors authentic problems to "purposes" that exist "in a context outside of schooling and educational purposes" (p. 151). This definition helps us understand why authentic problems often need additional structuring in order to be useful in the classroom. Importantly, authentic problems vary in (1) their complexity (i.e., the number and relatedness of variables), (2) their ill-structuredness (i.e., the degree to which there are multiple possible solutions and solution paths), and (3) their domain specificity (i.e., the degree to which solutions depend on specific disciplinary knowledge) (Jonassen, 2000). Over their educational trajectories, students encounter increasingly complex and domain-specific, well-structured problems (Barlow & Brown, 2020). Yet many problems encountered in engineering practice are also ill-structured. For instance, the ill-structured problem of viable fuel production from algae is being tackled in many ways, suggesting varied framings of the problem as an issue of growth rate, lipid potential, or lipid extraction (Hannon et al., 2010; Saad et al., 2019).

Strobel and colleagues' (2013) definition also helps us recognize authentic problems as situated by their contexts, and therefore, as sociotechnical. Sociotechnical engineering problems cannot be solved when reduced to just their technical components; instead, the technical is tangled with the social, sometimes in unpredictable ways (Jesiek et al., 2019; Law, 1987; Suchman, 2000). For instance, in the algal biofuel production context, the technical expertise—and therefore, the highly-skilled human resources—needed to operate closed cultivation systems (e.g., bioreactors) may make the less complicated—but also less efficient—open cultivation systems more appealing. Despite this interdependence of social and technical aspects, faculty often worry that students will struggle with the complexity, and faculty reduce or remove focus on social aspects. This commonplace reduction foregrounds the technical aspects and impacts students' development as engineers, leading them to expect problems in their workplaces to be solvable via technical and relatively linear methods (Kirn & Benson, 2018). Scholars have increasingly called for opportunities for students to grapple with entangled social factors, as doing so can create more points of entry, offer endemic checks on progress, develop

ethical reasoning, and allow students to make consequential decisions (Godwin et al., 2016; McQuade et al., 2020; Roberts & Lord, 2020; Rossmann & Stewart-Gambino, 2019). This last characteristic—supporting learners to have the agency to make consequential decisions—is of particular interest in the current study.

Agency, as classically theorized, is bounded by impervious structures (Giddens, 1984; Sewell, 1992). In this way, human capacity to make decisions is deterministically limited. Indeed, a common approach in PBL is to deliberately and systematically narrow students' agency to ensure they learn the intended content (Hung, 2006). However, when we want students to learn to frame problems and direct their own problem-solving process, such structures work against these aims. This issue has been cast as the assistance dilemma, a known tension between efficiency and floundering (Koedinger & Alevan, 2007). If we consistently introduce structures that prevent students from wrestling with truly ill-structured problems, as has been advocated (Jonassen & Hung, 2008), how will students be prepared to engage with such problems when they encounter them in their work? Recent research on scaffolding has raised concerns that some learning gains may be short term, and further, may be tied to lasting negative attitudinal impacts (Roll et al., 2018). As a result, scholars have argued for a need to explore alternatives to directive scaffolding, such as supports for discovery. For instance, in a study of four studio art teachers, Sheridan et al. (2022) documented ways teachers supported students' artistic agency. Using Reeve's (2016) framework of six ways teachers support students' agency, Sheridan et al. (2022) found that teachers set prompts for tasks that productively constrained students to explore and develop new skills. After setting an open-ended task, teachers acted as if they were unavailable, which encouraged students to find their own solutions rather than seeking guidance from the teachers.

Like Sheridan et al. (2022), we recognize agency as a key ingredient in the process of learning, especially in PBL and PjBL classrooms. However, just as self-efficacy is commonly treated contextually—that is, we expect people to vary in their confidence in mathematics, art, science inquiry, etc.—so too should agency (Du et al., 2021; Raffo & Roth, 2020). We extend our research that takes this approach (Svihla et al., 2021), situating agency by the types of decisions. This contextualization highlights that, for instance, making decisions about which font to use in a presentation, or even choosing which surgical device to investigate from a menu of options, are not the same as making decisions about what the problem is and how to approach it. Decisions vary not by their disciplinary context (e.g., science versus art), but in relation to problem structuredness (Jonassen, 2000). Framing agency describes the capacity to make decisions that are

consequential to how ill-structured problems are framed and solved (Svihla et al., 2021). Scholars have extended this notion of consequentiality to other contexts, such as making safer decisions in response to the COVID-19 pandemic (Johnson-Glenberg et al., 2021).

Rather than treating structures as impervious and reproduced, framing agency may be distributed across instructors and learners, as well as attributed to policies, scaffolding, materials, and other non-humans in the situation, in line with Schön's (1983) view of design as a conversation with materials. In this approach, students might negotiate their agency, for instance, with peer-reviewed research on algal biofuels or leave agency with the task and instructor.

Divergent-convergent participant and task structures

Participant structures refer to dynamic yet recognizable patterns of engagement, situated by the context (Goffman, 1974; Goodwin & Heritage, 1990; Jordan & Henderson, 1995). Within classrooms, teacher-driven participant structures are well described. For instance, Tabak and Baumgartner (2004) investigated how teachers foster more symmetrical engagements with students by acting as partners in science inquiry, sitting with them and making observations about what the students were investigating, like a group member. Tabak and Baumgartner (2004) linked symmetrical participant structures to students' uptake of scientific inquiry practices. Sheridan et al. (2022) used functional linguistics to document how teachers shifted between supporting students' agency and directing it across timescales: teachers indicated student ownership of past efforts; they shared possible future directions but left decisions with the students; and, with in-process works (present), teachers offered directives to students about specific strategies to meet the students' goals, paired with statements that mitigated teacher agency—a delicate balance given teachers' authority. Studies of participant structures also help us understand peer engagement and learning, such as how students negotiate about ways to solve problems, offer claims, warrants, and evidence in arguments, generate ideas about solutions, and evaluate one another's ideas (Cennamo et al., 2011; Grant, 2011; Henry et al., 2012; Toulmin, 2003).

These studies of participant structures illustrate four points that matter for understanding learning in PBL and PjBL classrooms. First, seemingly subtle variations can have a cumulative impact on how learners engage and what they learn. Second, participant structures are revealed through discourse. Third, participant structures vary in terms of who has agency, from asymmetrical teacher-directed interactions, to more symmetrical teacher-as-partner interactions, to small group work, to student-driven collaborative interactions (Patchen & Smithenry, 2015; Tabak & Baumgartner,

2004). And fourth, for our study purposes, it is useful to draw a distinction between macro participant structures—configurations designed and intended to support certain types of student interactions and learning—and micro participant structures—recognizable patterns in discourse. These macro and micro structures shape not only what students learn, but also their beliefs about the discipline and their roles as learners (Patchen & Smithenry, 2015). For instance, in a study of multidisciplinary health teams in PBL, analysis of group discourse revealed two micro participant structures regarding how students interactionally built knowledge together across disciplines and how they elaborated ideas when working with others in their same discipline (Imafuku et al., 2014). Similarly, a study of PBL in an undergraduate engineering course found that students believed that learning is a passive process—a belief that conflicted with common macro and micro participant structures in PBL (Henry et al., 2012). Such findings highlight the importance of attending not only to the problem itself, but also to the ways specific participant structures shape engagement.

We sought to form a macro participant structure that could enable students to learn with and from one another in ways that reflected the distribution of expertise in authentic engineering work, where collaborating professionals might have overlapping but not identical knowledge. We drew inspiration from the jigsaw classroom (Aronson, 1978), in which students first build up knowledge in a particular topic, and then bring that knowledge to their team to solve a problem. This approach promotes positive interdependence—the belief that one's success depends on their collaborators' success—by placing students in specific roles and dividing the task and resources needed amongst students (Felder et al., 2000; Johnson & Johnson, 2009). In the current study, we emphasized that students should explore different information and allowed them to do so in a range of ways across iterations, including meeting with students from other teams.

A key challenge in engineering design is making decisions. Unlike choices in well-structured problem-solving, design decisions are contingent and connected in complex ways, making many of them tentative. For instance, an engineer might choose a particular algal strain for its high lipid content, but then discover that algal strain is difficult to grow under local environmental conditions, an issue that may or may not matter depending on how the algae will be grown. One of the tools designers can use is a decision matrix, in which they develop and weigh criteria—like growth rate, lipid content, and suitability to the growth environment—then rate options, like algal strains (Farris & Jack, 2011). Decision matrices are commonly used in capstone design courses and have been investigated in a range of settings. For instance, undergraduates used decision matrices to choose a

television to purchase (Krupczak & Mina, 2013) and to make choices that jointly valued economics and environmental sustainability (Cornejo, 2017). Common to these examples, the criteria and their relative weights were not predetermined, but rather part of the task the students undertook. These examples clarify that even prior to significant coursework, students can make sense of the task of defining and weighing criteria, and then applying these to the options they have identified.

Purpose

In this study, we sought to theorize relationships between task and participant structures, agency, and learning. We contrasted three iterations of an undergraduate chemical engineering course that included a design project threaded throughout the course using variants of macro participant structures and task structures to support design decisions. Our aim was not to test our full instructional design, but rather to investigate the ways students attribute, distribute, and use their agency by closely examining interactional patterns. We conjecture that these forms of agency reveal much about how students interpret an authentic problem and their roles in framing and solving it, and what opportunities they have to learn in the process.

Methodology

We contrasted three variants of a learning design for its capacity to support interactional displays of framing agency. We conducted design-based research (DBR) to iteratively test our conjectures about students' agency, participant and task structures, and authenticity. DBR is an interventionist methodology that builds contextualized theory about how people learn through a process of instantiating that theory into curricular designs and iteratively testing them in typical learning settings (Brown, 1992; The Design-Based Research Collective, 2003). Broadly, we sought to investigate how task and macro participant structures—a decision matrix and collaborative and cross-team discussion—support sophomore chemical engineering students to engage with an authentic design problem in ways that showed framing agency. We specifically investigated the following sets of questions:

- To what extent do students use their agency to frame an authentic problem or offload problem framing onto the task and instructor?
- What micro participant structures differ between framing and offloading?
- How do different micro participant structures afford learning opportunities?

Setting and participants

The research was conducted at a Hispanic-serving institution in the Southwest United States. The participants were students enrolled in three semesters of a Material & Energy Balances sophomore chemical engineering course (cohort 1 = 66 in Fall 2016; cohort 2 = 70 in Fall 2017; cohort 3 = 70 in Fall 2018). The CATME tool was used to form teams, which varied in size as detailed in Table 1 (Layton et al., 2007). The course met three times per week for fifty minutes in a learning studio with round tables that seat nine students. Course activities commonly made use of the whiteboards that lined the walls.

Instructional design

Authentic barriers stand in the way of algal biofuels as a realistic strategy for sustainable energy (Hannon et al., 2010; Saad et al., 2019). An area of active inquiry, scientists and engineers continue to research ways to reduce resource demands and energy costs, innovating ways to enhance the growth and harvesting of algae and extraction of lipids for use as fuel. The algal biofuel design project tasked students to design a biofuel facility in a specific, rural New Mexico county using community resources like water sources and land space, while paying attention to constraints. Students

reviewed published studies to learn about options related to growing and harvesting algae and extracting lipids. As there are many possible options, we scaffolded students to investigate divergent options, including consulting across teams, and then to converge on decisions supported by a decision matrix in parley sessions. We refined our approach each time we taught the course, varying how we structured teams (Table 1) and supported students’ access to information (Table 2). The algal biofuel design project is a form of PjBL in which engineering practices like problem framing were emphasized (Dym et al., 2005; Mills & Treagust, 2003). The design project was threaded throughout the course, interwoven with and augmenting other course instruction (Gomez & Svihla, 2019). Thus, while meeting many of the hallmarks of PjBL—such as including a driving question that tasked students with designing ways to grow, harvest, and extract oil from algae for a rural community, need-to-know set by a launch video that introduced possibilities and barriers of algal biofuel, voice and choice in terms of algal species and growth and extraction methods, and opportunities for both instructor and peer feedback and revision (Larmer & Mergendoller, 2010; Marx et al., 1997)—the course was taught primarily using lectures, active learning, and problem sets.

| <i>Cohort</i> | <i>Macro participant structures</i> | <i>Observations leading to changes in next cohort</i> |
|---------------|---|--|
| 1 | Class was divided into three macro-teams aligned to a specialization (growth, harvest, or extraction); teams of three to four students worked within their specialization, consulting with teams from other specializations in jigsaws. | Students complained that they did not get to investigate all aspects (growth, harvest, or extraction). |
| 2 | Teams of seven to eight students, and all students worked on all aspects (growth, harvest, and extraction) in sequence, supported by cross-team discussions of choices and criteria. | Student engagement seemed shallow, covering too much material without depth. |
| 3 | Teams of seven to eight students, with one or two members focused on each specialization (growth, harvest, or extraction); discussions about criteria with others in the same specialization prepared students for team decisions about each aspect (growth, harvest, or extraction). | |

Table 1. Team Structures Across Cohorts and Brief Justifications for Changes

| <i>Cohort</i> | <i>Pre-parley</i> | <i>Parley</i> |
|---------------|---|--|
| 1 | Students independently research growth options (open pond versus bioreactor/closed system) out of class. | Teams generate and weigh criteria, then score options (open pond versus bioreactor/closed system) using their decision matrix to select their choice |
| 2 | Students independently research strains out of class. In class one week before the parley, they compare strains across teams. | Teams generate and weigh criteria, then score options (algal strains) using their decision matrix to select their choice |
| 3 | Students independently research strains out of class. In class one week before the parley, they compare criteria within specializations | |

Table 2. Task Structures

Data collection and analysis

Following IRB approval and consent, we documented students’ in-class interactions using video/audio recording. We recorded the instructor and one team in each cohort during all in-class pre-parley and parley activities—four class sessions for cohort 1 and five sessions for cohorts 2 and 3. Class sessions lasted 50 minutes. We recruited teams from those in which all members consented; because teams were formed using the CATME tool, non-consenting students were distributed across teams. IRB requirements limited us to the teams seated at tables around the edges of the room, where we would be less likely to accidentally record non-consenting students. This requirement eliminated two teams, resulting in a small possible set of teams (two or three) able to be included in the study. Past experience collecting data in the room also informed our recruitment order. We started with the team that was positioned best in terms of recording all members while minimizing audio from others in the room; if any member was unwilling to be recorded, we recruited the team at the next best location. Finally, we chose to recruit just one team per class in order to limit the disruptions to learning, as consenting and setting up cameras and audio recorders takes time.

In cohort 1, the team included four members, Josiah, Mia, Derek, and Elena (all names are pseudonyms). In cohort 2, the team included Andrew, Edina, Elijah, Kim, Samantha, one member who did not speak, and one who was absent. In cohort 3, the team included Ben, Duc, Winston, Marcus, Taylor, Lin, and one member who did not speak. As students were seated at round tables, we relied on multiple recording devices to capture usable audio. We used Descript software to automatically transcribe recordings, then merged these

to form a single time-stamped transcript. We corrected the transcripts, listening to recordings multiple times to document whole group and side-bar conversations, correct technical terms, and add filler language.

To identify how students used their agency during discussions, we turned to discourse analysis (Gee, 2014), which can reveal much about the interactional patterns that unfold in response to PjBL and PBL structures (Imafuku et al., 2014). Because our interest was in agency, we used a functional linguistics approach. Specifically, we started with an “agency toolkit” that Konopasky and Sheridan (2016) developed based on interviews with adults discussing what prompted them to drop out of school. The agency toolkit draws attention to the subjects of sentences, verbal forms, and other ways that speakers display or mitigate their agency. We worked iteratively and across datasets to develop our three-stage approach (Figure 1), which deliberately shifts the unit of analysis across stages (Schiffrin, 1997). We reviewed data individually, then discussed what we noticed about agency, influenced by the agency toolkit (Konopasky & Sheridan, 2016). We diverged from Konopasky and Sheridan’s (2016) approach, however, using a more situated method to understanding agency, which we have reported elsewhere (Svihla et al., 2021) and summarize here. Konopasky and Sheridan’s (2016) analysis was of retrospective accounts, while we worked with in-situ, interactional data. While their interview data was situated as information gathering, our participants’ activities were structured by the task, instructor, and information, and in reaction to one another. They found that participants tended to distance themselves from unsavory actions, such as participation in gangs, thus mitigating their agency by placing themselves amongst many or using the generic “you.” Conversely, we found many uses of the generic

“you” in students’ talk, commonly in reference to contexts of use. For instance, Josiah explained concerns he found about closed systems for growing algae: “They have issues with getting the cultures from the bottom up to the top, unless you invest in some sort of expensive device, a bubble column or something to mix the cultures.” He switched between “they” and “you,” ambiguously offering his teammates tentative participation in the research he read and inviting them to change their minds.

Konopasky and Sheridan (2016) showed how their participants ultimately shared stories of and from a single point of view, whereas our students worked collaboratively, as is common to design. Their participants shared their navigation of their own educational goals, as opposed to our students, who were provided with a design project by a course instructor. Konopasky and Sheridan (2016) treated “I” and “we” as relatively interchangeable, but in collaborative design settings, the shift between these pronouns is distinctive, indicating a difference of opinion or ideas offered to the

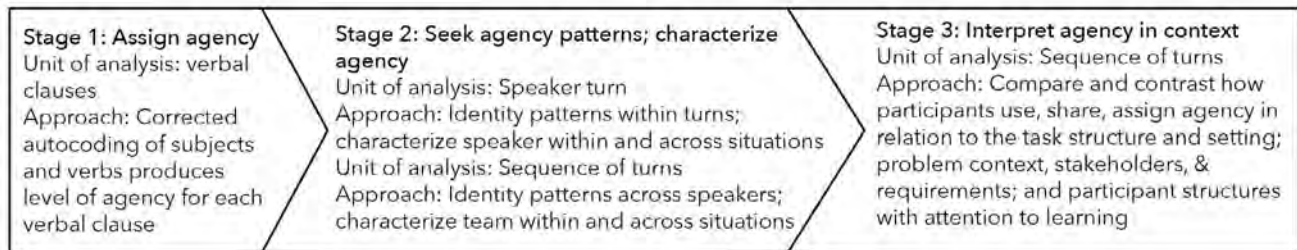


Figure 1. Three-Stage Analytic Process

team. For instance, Taylor made the suggestion, “I wanted to focus on broader, um, family types of algae before I focus on smaller strains, because if we focused on larger family types, um, we would be able to compare—more of us would be able to compare, um, similar family types with the same criteria.” In statements like these, students introduce an idea showing individual ownership using the pronoun “I” and then invite their teammates to join them using the “we” pronoun.

We initially coded data at the turn-level. However, this approach masked agency shifts that occurred within utterances. Thus, in our three-stage process (Figure 1), our first unit of analysis was verbal clauses, which we placed in an Excel file with columns for sequence, speaker, and transcript. Next, we used nested formulas “IF,” “ISNUMBER,” and “SEARCH” to autocode for certain words (Table 3) and automatically assign a level of agency based on the combination of subject and verb (Table 4). We sorted the data by assigned level for review, making expected corrections; in particular, the autocoding could not distinguish between specific and generic uses of “you,” “you” as subject versus object (e.g., “You said” versus “I said to you”), and the many nouns that can serve as sentence subjects, resulting in a range of 80-90% correctly autocoded verbal clauses. Once corrected, we sorted this highly reliably-coded data to its original sequence for our next step of analysis.

In our second stage, we shifted to speaker turn and sequence of turns as the unit of analysis. This approach allowed us to examine patterns within and across speakers, to characterize speakers within and across situations,

and to compare teams. For instance, we identified common sequences of highest and attributed agency, reflecting a speaker claiming agency for an action then offering an idea (“I read in the article, too it—it is never cloudy”) or stating a preference and offering their reasoning (“I feel the bioreactor would take care of those problems”).

We treated these first two stages as wayfinding in larger datasets to orient ourselves as we began a third stage of more typical discourse analytic work of interpreting talk in context (Gee, 2014). The first two stages situated a segment as characteristic or uncommon, which in turn aided in selecting data for more careful attention. We attended to how the speakers used agency to accomplish aims, thereby illuminating much about the ways they interpreted and negotiated task and participant structures. We examined what participants treated as negotiable and how they engaged together to make decisions related to their project and the task at hand. We used color coding within vignettes to anchor our first stage analysis (Figure 2).

Trustworthiness and credibility

We used established methods for our study, conducting them in ways that contributed to credible and trustworthy inferences in interpretive qualitative research (Lincoln & Guba, 1985). The authors met frequently over three years to plan, carry out, and debrief data collection and analysis. Though we focus on a subset of data in this paper, our data corpus allows for triangulation. As we embarked on analysis, we worked independently, then compared results,

| <i>Term</i> | <i>Function</i> |
|--|---|
| I | First person subject |
| We | First person plural subject |
| Third-person (He, she, they, it, that, nouns-as-subjects) | Speaker places object, environment, or other actor(s) as subject. Low autocoding accuracy as many nouns are not detected and “that” has other functions |
| Specific “you” | Speaker uses a specific “you” as subject of a sentence. |
| Generic “you” | Speaker uses a generic “you” as subject or places self among many others. |
| Told to, needed to, instructed to, have to, need to, must, needs to, has to, had to, required, supposed to, had to, got to, gotta, can’t, cannot | Speaker uses modal obligation verbs or passive construction, indicating a lack of control over the situation |
| Could, might, should, can, going to, would, will, shall, may, want to, gonna, wanna, *’d, *’ve, *’ll | Speaker uses modal verbs that indicate potential for control over the situation |

Table 3. Autocoded Terms and Their Functions in Stage One of Our Three-Stage Process

| <i>Terms (example)</i> | <i>Score</i> | <i>Initial interpretation</i> |
|---|--------------|---|
| I + full control verb (I did that / I do that) | 10 | Highest agency |
| I + potential control verb (I could have done that / I could do that) | 9 | High potential agency |
| You + full control verb (You do that / You did that) | 8 | High agency |
| You + potential control verb (You could do that / You could have done that) | 7 | High potential agency |
| You + no control verb (You have to do that) | 6 | High agency, commanding another |
| We + full control verb (We did that / We do that) | 5 | Shared high agency |
| We + potential control verb (We could have done that / We could do that / Let us do that) | 4 | Shared potential agency |
| Third-person subject OR generic “you” + potential control verb (It could be / It could have been) | 3 | Potential agency shared with requirements, materials, stakeholders, others. |
| Third-person subject OR generic “you” + no control OR full control verb (It must be / It must not be / It is) | 2 | Agency attributed to requirements, materials, stakeholders, others. |
| I OR we + no control verb (I have to do that / We have to do that) | 1 | Agency offloaded to other |
| Uncodable | 0 | Not interpretable |

Table 4. Levels of Agency Based on Verb and Subject Terms in Stage One of Analysis

discussing discrepancies and consulting with other experts and literature. For instance, in determining which verbs suggested potential control or no control, we repeatedly revised the list of verbs, consulting with researchers from another field who use linguistic modality in their work (Vigus et al., 2019). We developed our analysis across a set of projects; specifically, the first author brought this approach to datasets collected in a project-based design-build high school, a capstone biomedical engineering design course, and an Air Force Research Laboratory. This process provided deeper peer debriefing and scrutiny and necessitated more detailed audit trails to allow the approach to extend across such projects. For instance, we developed a detailed step-by-step set of instructions and code log that accompanied our Excel-based analysis, enhancing the transparency of our approach. These instructions communicate to new researchers what, how, and why we did analysis in this manner—meeting the standards of transparency for qualitative analysis (Tuval-Mashiach, 2017). The third stage of analysis relies on thick description (Geertz, 1973) and transparency (Tuval-Mashiach, 2017), rather than inter-rater reliability.

Results

To answer the first two research questions, we share vignettes from each of the three teams/cohorts, then draw comparisons across teams/cohorts. In these vignettes, taken from the first parley sessions in each cohort, we draw attention to micro participant structures and the displays of higher and lower agency discourse that comprise them. In the cross-team analysis and discussion that follow our initial results, we answer our final research question, considering how different micro participant structures afford learning opportunities.

Cohort 1

Although they were tasked with filling out the decision matrix, and Josiah inquired to the team about it (“Do we need to make this matrix right now?”), his teammates interpreted their task as discussing their different ideas prior to referring to the matrix. The students in the cohort 1 team were divided: Elena and Josiah preferred to use an open pond to grow algae, and their peers preferred bioreactors (also referenced as “a closed system”). In discussing their reasoning, they commonly attributed agency to others and the environment, while owning their efforts to find these requirements. In vignette 1 (Figure 2), Mia used high agency to reference her choice of a bioreactor, then introduced requirements using verbs that showed no control to defend her choice. She used more tentative language in noting the complexity of such systems and expertise needed. Derek, who agreed

with her choice, emphasized her information by revoicing it and drawing attention to the issue of environmental interaction and dependency. As they discussed further, they continued to attribute agency to the generic “you,” the algae, and generic settings (“the environment”). In doing so, they referenced research they found, creating opportunities to learn from one another about the growth conditions given different choices. We characterize this micro participant structure as attributional framing, as members introduce ideas and attribute them to external sources, potentially altering the problem frame.

A few minutes into the conversation (Figure 3), Mia shifted from her argument that an open pond would require too much space to acknowledging that space might not be an issue given the specific context—“a small community.” In doing so, she shared agency with her team. Elena took up this opportunity to draw attention to the specifics of the rural context. Elena’s “we” positions her as part of the rural community, which invites her team to do likewise. This stance suggests some accountability to and empathy for the community. Further, this stance provides evidence of Elena treating the scenario as an authentic problem that exists beyond the classroom context. Josiah then interjected, situating his preference as the shared, team solution by leading with “we,” using a verb suggesting they lacked control over the choice, and presenting his idea as solving the issues noted. By then launching into a list of features and attributing some agency to the research he read (“they say”), he held the conversational floor long enough to kindle interest in open ponds. Here, in addition to attributional framing, we also describe shared framing as another micro participant structure in which members introduce arguments or ideas persuasively from the perspective of stakeholders impacted by the problem.

When prompted to consult with other teams—a shift in participant structures—they had still not made a decision. They used their agency to ignore this instruction, exemplified when Josiah said, “Shh. Let’s just keep discussing.” Josiah agreed to go with the majority vote, and Mia asked for cons to list related to bioreactors (closed systems, Figure 4). Elena again, tentatively, brought the specific rural context into consideration, owning her concerns about the bioreactor. As Mia considered this context, Josiah offered more cons, showing high agency about sourcing them from readings, while attributing agency to researchers, the algae, and the environment. In questioning the ongoing discussion, Derek shared agency with his peers. Mia’s reply showed individual, tentative agency, positioning her stance as more open than her prior utterances suggested. Indeed, after Josiah offered further information from articles he had read, Mia changed her mind, expressing tentative agreement that the open pond

Mia: I feel like this amount of space—what I was reading from articles was that you have to keep expanding, because the algae gets like hungrier, and you have to have more space. And you have to have the algae laid out because the algae gets layered. The algae beneath the top layer, uh it's not—light doesn't reach it. So, you have to like have a lot of space spread out. So I just feel like if that realistically just a huge environmental cost. [...] Yeah, so it would take a little bit more expertise, maybe a little bit more upkeep. So, it's probably like more labor-intensive. I just think like for the efficiency—it would be like way more efficient and

Derek: //You'd be producing more.//

Mia: less space, less impact on the environment. It's not exposed to the environment whatsoever, so we have, really, no potential for it to interact.

Derek: It's not dependent on the environment.

Mia: Yeah, it's not gonna

Derek: If it rains one day

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 2. Cohort 1, Vignette 1, Beginning at [01:00] (mm:ss). Attributional Framing Micro-Participant Structure

Mia: Yeah, spread out, and then there's tons of space required.

Derek: If it's too thin, then evaporation's gonna take away most of your water.

Mia: For a small community, but the space wouldn't be as much of an issue, which is what, I guess, we're looking towards. But, on a larger scale –

Elena: Consider like how we would pay for it. We're in a rural community with no one like who has money, how would we pay.

Josiah: We just gotta make an inclined pond—that takes care of both of those issues.

Derek: What does?

Mia: What does?

Josiah: Using an incline pond, instead of a flat raceway pond. Using an open-air system. I know you guys are talking about using a closed system, but they say if you use a flat-incline pond, it offers better turbulent flow, shallower culture depth, they get better sunlight, and it reduces the thermal inertia culture allowing for a more rapid temperature increase.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 3. Cohort 1, Vignette 2, Beginning at [06:00]. Shared and Attributional Framing Micro-Participant Structure

approach would suffice, given the context. Again, in this vignette, we notice the micro participant structure of attributional framing.

Cohort 2

The team in cohort two began their session filling in their individual choices for algal strains on a shared GoogleDocs worksheet that included a sequence of steps. After three minutes, Kim introduced the second task, “We need to write the criteria to these steps, so what are the criteria that we’re looking for.” Throughout, when students referred to the task

at hand, they typically used this kind of lowest-agency talk, leaving agency with the task or instructor. In proposing criteria, they expressed uncertainty, first about the independence of criteria, like growth rate, lipid content, and biomass, and second about the units, as members quickly offered that they had numbers in percentages, grams/liter, milligrams/liter/day, and milligrams, as well as qualitative assessments, like high yield. Amidst this ambiguity, Samantha suggested Kim take the lead in asking questions and assembling the information, tentatively positioning herself and her other peers as tracking down information (Figure 5). Kim agreed, but

- Mia: Ok **what** do you um—**what would** you guys say another another **what’s** another major con with having a closed system, other than **it’s** expensive? Cause **I’m** like
- Elena: **I** think the dark-light system, **I** mean **it’s** expensive.
- Josiah: **I** got a bunch a bunch to say
- Elena: **Both of them** are **gonna** have their problems with cost. **I** just think **it’s** **gonna** be too complex, especially in like a little rural farmland community? If **I** build like this crazy thing—**People** don’t know what **it** is then **they’re** not
- Mia: If **this** was like, **I** mean **I** guess **I** could see if **this** is an isolated like project—which **I** guess **it** kind of is—so **I** could see that. **I** think that it—**both of them** have
- Josiah: Hey, you want some more cons?
- Mia: Yeah.
- Josiah: So, **I** read that **there’s** many—**there’s** many issues associated with scale-up. Like-of-so like So right now, most photo-like **the phot-bio-reactors** are small. ish. Like the size of like
- Mia: //Yeah//
- Josiah: one building. you know, **they’re** not, like, large-scale. And so **it** said that some of the issues that **that** are involved with scale-up include um photorespiration—so if **they’re** having trouble with removing O2 from the systems
- Mia: Okay
- Josiah: So that, when **that** builds up then **the plant** no longer uses CO2 to make what **it** needs to make, and **it** just uses the O2 to do photo-respiration.
- Derek: Wait, are **we** still trying to decide which one **we** are
- Josiah: Well, **she’s** asking for cons about
- Mia: ‘Cause **I** wanna—yeah **I** wanna hear more
[15:00]
- Mia: **I** think considering the situation—it’s a small community—so **I** think the difficulties **that would** arise with having an open pond, in large-scale, don’t really matter in this case. Even though, **I** think, in large-scale **I** would use a bio-reactor, because **it’s** more efficient, easier to control, and takes more expertise and stuff like that. **I** guess **we’re** looking at a real community, **that’s** like 10,000 people—rough estimate—an open pond would suffice, **I** think, plenty well. And **it** would be much less expensive for a small pond.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 4. Cohort 1, Vignette 3, Beginning at [10:45] and Continuing at [15:00].
Attributional Framing Micro-Participant Structure

Samantha: So do you want to just ask us questions and kind of assemble it and we'll all find out information if we don't have it?

Kim: Yeah!

Samantha: Yeah?

Kim: And then we can just all be typing in here at the same time.

Samantha: Oh yeah 'cause it's a-It's a group thing.

Kim: Yeah! Yeah, it's GoogleDocs so you guys can be writing in there when I'm writing.. and if you have questions, it's all here.

Samantha: The one thing that we have to decide is just the criteria so far I've only listed two, and I'm gonna go back to the old documents like

Kim: Oh yeah.

Andrew: There's still 3 though I thought.

Samantha: So there's like 4 criteria

Elijah: On Google Docs. I see that.

Andrew: Do we need more than 3? Like is there an amount we actually need?

Andrew: [30 sec later, to instructor] Are there a certain amount of criteria we have to have?

Instructor: As many as you think are important.

Andrew: Oh okay. Alright.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 5. Cohort 2, vignette 1, beginning at [06:00]. Shared Task Negotiation followed by Offloaded Task Micro-Participant Structures

amended the task, using an inclusive “we” to invite everyone to make edits. As they oriented to this task, they left agency with the instructor, first in noting, “we have to decide,” and then by querying the instructor about how many criteria they needed to fill in. This vignette is characterized by two micro participant structures. First, the team engaged in shared task negotiation, a structure that is procedurally-focused and negotiated amongst members, but does not include effort to frame the problem. Next, Samantha’s direction (“we have to decide”) introduced a structure that we denote as an offloaded task, in that the way they work was oriented toward completing a well-structured task as set by the instructor.

As they continued to work, they blurred the lines between selecting criteria and evaluating algal strains, in part to assess whether their criteria were usable, given the varied units they had to reconcile with. Characteristic of this team, many of their turns were brief, with longer turns typically focused on making sense of their role in completing the task (Figure 6). For instance, the task indicated that in addition to defining criteria and evaluating algal strains, they also had to decide how much to weigh each criterion and what score to assign each strain. Samantha conflated weighing criteria and assigning scores, again leaving agency with the task, but then

offering a tentative suggestion for how to assign weights. Andrew corrected her, using “we” to distribute responsibility for the task. Kim clarified that task, attributing the agency to the task. Once resolved, they quickly came to a consensus on weighing. Here again, we observe the offloaded task micro participant structure as students were oriented to correctly completing the task set for them.

As they tried to score their algal strains, however, they continued to find gaps in their notes. They did not take up Samantha’s earlier suggestion to seek out missing information (Figure 5). Instead, Samantha suggested omitting growth rate as a criterion (Figure 7), using “we” and tentatively inviting her peers to consider this change. This suggestion was met with immediate support from Andrew. Kim acknowledged that she considered growth rate to be an important criterion, but also that they lacked equivalent information. With Edina’s concern about time—offered as a shared concern—Andrew invited the team to recognize that they thus had one option, deleting the criterion. This choice does not meet the instructor’s earlier response to Andrew’s question about how many criteria they needed, which was, “As many as you think are important” (Figure 5). By eliminating a criterion that they knew to be important, they treated the task

Samantha: So we have to rate each criteria with a weight from 0 to 3 right? Sooooo, the most important one. Do you want to give that a 3 and choose the least important one

Andrew: Well what we do with rating is we say how how good this particular strand is at that

Samantha: Right, but we have to decide a weight too.

Andrew: Yeah

Samantha: How important it is.

Andrew: Exactly yeah.

Elijah: So I'd say

Andrew: But the weight's not to 3. Weight's a percentage of 1

Kim: The sum has to be 1, depending on the weights. So this has to be

Andrew: So I'd say it's most im-

Kim: 1

Andrew: So do you guys think .4 since that's our most important

Samantha: I think .4

Kim: Ok.

Andrew: I agree with that.

Kim: I'll go with .4, so we have .6 left. Growth rate. What point do you give on for that one?

Elijah: Uhh .3

Samantha: 0.3

Edina: 0.3

Andrew: 0.3

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 6. Cohort 2, Vignette 2, Beginning at [14:00]. Offloaded Task Micro-Participant Structure

as inauthentic. They did not view their decisions as consequential outside the classroom. As in the first vignette for this team, we notice both shared task negotiation, as they contended with missing information, and an offloaded task, as they faced time constraints.

As they tried to score their algal strains, however, they continued to find gaps in their notes. They did not take up Samantha's earlier suggestion to seek out missing information (Figure 5). Instead, Samantha suggested omitting growth rate as a criterion (Figure 7), using "we" and tentatively inviting her peers to consider this change. This suggestion was met with immediate support from Andrew. Kim acknowledged that she considered growth rate to be an important criterion, but also that they lacked equivalent information. With Edina's concern about time—offered as a shared concern—Andrew invited the team to recognize that they thus had one option, deleting the criterion. This choice does not meet the instructor's earlier response to Andrew's question about how many criteria they needed, which was, "As many

as you think are important" (Figure 5). By eliminating a criterion that they knew to be important, they treated the task as inauthentic. They did not view their decisions as consequential outside the classroom. As in the first vignette for this team, we notice both shared task negotiation, as they contended with missing information, and an offloaded task, as they faced time constraints.

Cohort 3

Like cohort 2, the first task for the cohort 3 team was to list their individual choices for algal strains. The team began by discussing their individual experiences during the pre-parley, where they consulted with students in their same specialization, but outside of their team; they described the pre-parley as "difficult" because everyone they spoke to had different strains and little sense of how to compare them. This problem prompted them to recognize the need for similar information across different strains, suggesting that the revised pre-parley activity (Table 2) functioned as

Kim: It was hard to find a lot of this information especially in units that we can compare all of it in
 Samantha: Should we just change the growth rate criteria and do something that we all have?
 Andrew: Yes!
 Samantha: Do you want to do that?
 Kim: I mean growth rate is important right? But I mean, what do we all—what do we all have?
 Edina: We don't have time to change it.
 Kim: Well then.
 Andrew: Well then we're probably just going to have to delete it.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 7. Cohort 2, Vignette 3, Beginning at [23:00]. Shared Task Negotiation followed by Offloaded Task Micro-Participant Structures

Marcus: It would produce hydrocarbons versus lipids which is what we want.
 Taylor: But there's a trade-off for that.
 Marcus: Hydrocarbon is what biodiesel is made out of. That's like what we are doing if we were making omega 3 oil, lipids would be fine but
 Taylor: There is a trade-off for that, though. Because if you dif—if you, um, limit the amount of nitrogen in the system, it limits growth rate. So there's this trade-off between if you want to produce more—
 Marcus: //Like a balance?//
 Taylor: of the algae, or if you want to produce more lipid per algae. So there is—per algae cell. So they don't know which is more efficient if they should increase growth rate, or should—if they should increase individual lipid content.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 8. Cohort 3, Vignette 1, Beginning at [05:00]. Blended Shared and Attributional Framing Micro-Participant Structures

intended. Rather than concisely listing their choices, the students shared their reasonings about potential choices, displaying highest-agency talk paired with third-person references to research (e.g., Taylor: “It seemed that it’s easy to cultivate, so far as I found.”). They discussed and considered strains in various conditions (Figure 8), attributing agency to researchers, algae, and the generic “you,” then holding these ideas against their shared aims. In discussing research they located, they also treated that knowledge as somewhat tentative. For instance, Taylor explained that “They don’t know.” In addition to referencing gaps in the research, the students

also noted the bounds of their own understanding, displaying ownership over their uncertainty. For instance, Marcus, after summarizing details of a study he found, could not answer a peer’s question, stating, “That part I’m not sure.” In this vignette, we notice blended attributional and shared framing micro participant structures as students introduce ideas from their research and evaluate them from shifting perspectives. As they continued to share their individual choices, they showed high agency for their choices, while attributing agency to research sources (e.g., Marcus: “The reason I like bronni, from, like, the extraction perspective, is

because I have an idea for extraction, which I already shared with [Benjamin], which is like acoustics. So, like, um, you can separate oil from water and using acoustic signals.”)

After 17 minutes, during which they had all discussed their individual algae choices, Taylor invited the team to shift to the second task, choosing criteria (Figure 9). In terms of micro participant structures in this vignette, the students’ collective focus on procedure is characteristic of shared task negotiation, while their attention to the comprehensiveness of their criteria and its potential to guide their decision displays shared framing. Ben’s comment, “we have spaces,” suggests shared ownership over a generative task. Indeed, in the ensuing discussion, the members displayed high individual agency at some times and shared agency at other times, inviting members to consider particular criteria. For instance, Marcus suggested reusability, defining it in terms of a locally-scarce resource: “Like if we put water in, can we take that water out.” To this, Lin agreed, stating that it was “ideal in New Mexico.”

In just two minutes, they generated and discussed six shared criteria, yet still sought more (Figure 10). In this vignette, we again notice both shared and attributional framing micro participant structures as they refined criteria from varied perspectives. Winston offered an idea about storage in a way that suggested he did not personally research it but was wondering if someone did. In evaluating the idea of storage, Winston and Marcus took ownership, positioning themselves as the people responsible for storing and funding aspects. Ben, followed by Winston, then attributed agency to others for such actions. We consider this placing of self in and out of the context to be potentially productive, providing a chance to consider the problem from a stakeholder point of view, while also acknowledging their role as designers, not stakeholders. This shift also suggests the members were treating the problem as existing authentically external to their class.

Taylor: Sh—shall we focus on criteria now
 Marcus: Yeah, let’s jump to criteria now.
 Winston: Biomass con—concentration. Is that part—one of those criteria.
 Taylor: // [to Lin] Because that’s how we’re going to make our decision.//
 Marcus: Yeah, so he [pointing to Ben] was saying efficiency, but I think yield—yield is, uh, a very.
 Ben: So you’re talking about extraction YIELDS, right?
 Marcus: Yeah. Like, when it’s all said and done, how much do we have versus how much-
 Winston: How much biomass is there.
 Ben: Okay, so two—we have spaces for, at least, uh, twelve pieces of criteria. So, if you think. Just throw something out, what do you have on there?

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 9. Cohort 3, vignette 2, beginning at [17:00]. Shared Task Negotiation and Shared Framing Micro-Participant Structures

Ben: Like, what else do **we** have? So, **we** have six, so far: cost efficiency, extraction yield, hydrocarbon yield, reusability of byproducts, growth rate, and versatility.

Winston: **I** don't know if **we've** done research on this, but **I** think storage **would be**—

Ben: Okay.

Winston: How can **we** store it?

Marcus: And also, like, the expense of what **we** **have to** put in. Well, **I** guess **that's** in efficiency.

Lin: **That** is a cost efficiency.

Ben: So, how do **we** **wanna** word that? Storage, storing...

Winston: Storage? **I** don't know. Shelf life?

Ben: **It'd be**, like, product storage? Or **you** want it—the, like **what** is it

Winston: Like, like, if **you're** calling them today, does **it** **have to** straight to industry to be processed, like, tomorrow, or on that set day, you know?

Marcus: Yeah

Winston: Or **you can** wait for, like—**you can** stock them in a warehouse for, like, a week or so.

Ben: So, you wanna call it—

Winston: //Shelf life?//

Ben: like a raw- raw product. Shelf life?

Marcus: Shelf life. **That's** a good one.

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 10. Cohort 3, Vignette 3, Beginning at [19:00]. Shared and Attributional Framing Micro-Participant Structure

Additional evidence that the team approached the problem as authentic comes from discussion of Marcus' proposal, that they should invent completely new methods of biofuel extraction and focus on uncommonly used algae (Figure 11). Marcus owned his opinion clearly, invited members to consider his opinion, but also offered tentative willingness to follow the team's preferences. Taylor used lowest-agency talk to counter his proposal, while Winston cast the team into stakeholder roles, raising concerns about the potential cost associated with innovation. The students wrestled with their roles and the tension of balancing cost and their interest in inventing. Even Taylor's statement of making "the frontiers of research...more efficient" suggests either his own interest in innovation or an effort to satisfy his teammate's interest in innovation. Ben's suggestion displayed shifting agency, first showing ownership, then offloading agency, then sharing agency with his team, before attributing agency to the context. This vignette again shows the micro participant structure of attributional framing, and introduces what we have termed shared role framing, in which members tentatively position themselves and their teammates as innovators

versus those working in industry who simply apply known techniques. This positioning acts as persuasion for more challenging and innovative problem frames.

Cross-team analysis and discussion

Micro participant structures and framing agency

We address our final research question, which considers the learning opportunities afforded by different micro participant structures (Table 5), and share implications of these, before discussing our findings and implications more broadly. The micro participant structure of offloaded task, observed only and often in the cohort 2 team, does not contend with problem framing. However, this participant structure does provide opportunities for students to check the accuracy of their independent research and learn facts and concepts from their peers. Knowing that they would need to contribute researched ideas to their teams, students generally came to class prepared with gathered information. However, uncertainty about how this information would be incorporated meant that not all gathered data were in comparable forms. Despite students making references to on-the-fly searches to fill these knowledge gaps, we did not observe

Marcus: My opinion is to do something novel. Like, I feel like if we're gonna do something, it should be—there should be a “wow” factor. Like “wow,” like I mean, but that's my opinion if you guys wanna go for something that's like already done in industry, that would be easier, then we can do that. Like. That's just my opinion.

Taylor: Well, we can't—we can't work off of nothing. So like the basic techniques we use already for algal—algal extraction and harvesting, we have to implement, because we can't just work from ground zero. [...]

Winston: And that's the thing. Are we gonna have—are we gonna have the ability to—to be able to pay? There's some innovative research being done in—in certain areas as far as //cultivating and extraction, can we add that to//

Marcus: //Like, are we gonna continue doing the same stuff for all these years that they've been doing// or are we gonna engineer something NEW? Are we gonna, you know, bring our knowledge, and our expertise to this to design something that's never been done?

Winston: And I think that's what the overall project is about. Is—are we going to be able to engineer something new and creative and—

Marcus: And novel.

Winston: And novel in design?

Taylor: I think, um, our job is to mainly—I don't think we're going to—p-per se engineer completely new technology. I think what we're gonna do is we're gonna take the frontiers of research that's already been done, and make it more efficient by the process that we employ.

Winston: And apply it to our project.

Taylor: Right, exactly.

Marcus: Yeah, I see what you're saying like we can't just invent something out of the blue.

Taylor: Yeah.

Winston: No.

Marcus: But, at the same time, we shouldn't follow a process that's, like, just “Everybody knows you can do this with algae,” like what are you showing, like this has no information that's new.

Ben: I—I think, you know, a large aspect of this is, here's why we're doing different locations, is because we're looking at applying the same concept but forming it to this region, because you can't pick a species that's gonna work in the south and have it—expect it to work in the north, you know, with maximum efficiency

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| High agency marker. First person singular subject |
| Shared agency marker. First person plural subject |
| Framing agency marker. Verbs show potential control |
| Low agency marker. External person/object subject |
| Low agency marker. Verb indicates lack of control |

Figure 11. Cohort 3, Vignette 4, Beginning at [22:00]. Shared Role and Attributional Framing Micro-Participant Structure

them doing such searches. Instead they chose to eliminate criteria they previously believed to be important (Figures 6 & 7). The offloaded task structure, especially when observed with the shared task negotiation structure, may be common in many PBL group activities, including jigsaw (Aronson, 1978), when students anticipate their role to be problem solvers facing well-structured problems.

The attributional framing micro participant structure, in common with the offloaded task structure, provides opportunities for students to learn on their own and from their peers as they share information from their individual research.

This structure may consequently alter the problem frame, as well. Students not only bring information in, but also use that information to support or challenge the problem frame and/or propose a design idea—we use the term “design idea” deliberately for its breadth; design ideas include tentative design solution ideas or ideas about the problem itself. This micro participant structure therefore provides practice opportunities for students to develop reasoned arguments, differentiate between different problem frames, and evaluate the potential of different solutions to meet needs—tasks that

experienced designers perform regularly (Cross, 2004). As such, this structure is a core component of developing framing agency.

Next, the shared framing micro participant structure, in contrast with attributional framing, does not involve citing external sources and information gathered. Instead, students reference a particular problem frame, making aspects of this frame apparent. The students typically use shared framing to support or counter a design idea or draw attention to the coherence between particular frames and solutions. This structure provides opportunities for students to practice core design skills, like bounding problems and evaluating tentative solutions in terms of meeting identified needs (Cross, 2004). Like attributional framing, shared framing is a core component of developing framing agency.

Finally, we described shared role framing, observed in the cohort 3 team only. In this structure, students position themselves as particular types of designers in a bid to frame the problem in a particular way. However, because we observed few instances, we treat this micro participant structure as somewhat tentative and in need of further investigation, even though it aligns well with research showing that experienced designers tend to frame problems in more challenging ways (Cross, 2004). This structure has the potential to provide opportunities for students to try on and shape their roles as designers. For instance, some may approach design from the stance of innovator, empathizer, or with a critical mindset (Godwin et al., 2016). These stances allow students to make connections between these identities and their futures in engineering and may offer evidence of a link between framing agency and identity work. Our related work explores such connections through surveys.

| <i>Micro Participant Structures</i> | <i>Discursive markers</i> | <i>Examples</i> |
|--|--|---------------------------------------|
| Offloaded Task: Offloading to the task, instructor, or time constraints in ways that avoid contending with problem framing. | Modal obligation verbs (“have to,” “must”) display lack of control. | Co. 2 vign. 1-3 |
| Shared Task Negotiation: Negotiating task procedures with members. Task-oriented. Does not include effort to frame problem, though decision process may open or limit additional framing. | Use of first-person plural (“we”) subject. | Co. 2 vign. 1, 2 Co. 3 vign. 2 |
| Attributional Framing: Attributing agency to information gathered from expert, external, reliable sources—often while holding ownership of the source—to support, counter, or introduce a design idea. May alter problem frame. | Clauses that bring information and design ideas into the frame (“algae get hungrier...you have to have more space”), often with first-person singular subjects (“I read”). | Co. 1 vign. 1-3 Co. 3 vign. 1, 3-4 |

Table 5. Micro Participant Structures

| | | |
|--|---|--|
| <p>Shared Framing: Inviting members into a frame—often with tentative or persuasive talk—to support or counter a design idea or reveal the (mis)fit between a problem frame and particular solution. Sometimes this approach involves taking up the position of a stakeholder. May alter problem frame.</p> | <p>May include shifts from generic “you” to “we” as subject, use of modal obligation and possibility verbs.</p> | <p>Co. 1 vign. 2 Co. 3 vign. 1-3</p> |
| <p>Shared Role Framing: Inviting members to take up particular roles in order to frame the problem in a specific (e.g., more challenging) way. May alter problem frame.</p> | <p>Use of first-person plural (“we”) subject and modal verbs (“could,” “gonna”) that express possibility</p> | <p>Co. 3 vign. 4</p> |

Table 5 continued. Micro Participant Structures

These micro participant structures suggest implications for PBL and PjBL that involve ill-structured problems. While the offloaded task structure does provide opportunities for students to share information with one another, the attributional framing structure greatly expands upon this; students compare, evaluate, and reason with information gathered by their peers in ways that can contribute to their understanding of working with ill-structured problems. Instructors might listen for such conversations diagnostically and employ strategies proposed elsewhere to support learner agency, such as giving students time to work out ideas on their own and reassuring them about expectations (Reeve, 2016; Sheridan et al., 2022). Next, we discuss the macro participant and task structures that may have produced these differences in micro structures.

Macro participant and task structures that foster framing agency

The cohort 1 team dealt with a lower-complexity task (Jonassen, 2000), choosing between limited options for ways to grow algae. While cohorts 2 and 3 dealt with a more complex task (choosing an algal strain), these two cohorts did

so with different macro participant structures. In pre-parley activities, the cohort 2 team, whose members anticipated having to explore every aspect (growth, harvest, extraction), had compared strains with members of other teams, whereas the cohort 3 team, whose members each had specializations in one aspect, had compared criteria with members of other teams.

We characterize the cohort 1 and 3 students as exhibiting framing agency because they negotiated decisions tentatively by considering various implications of their choices through the micro participant structures of attributional and shared framing. They brought multiple ideas into the conversation, thus framing and reframing the problem. Among these, they considered the intended context—a rural community—and specific ways their decisions did or did not fit within that context, meaning they shared their agency with the context. Notably, in using their agency to shape the problem, they also maintained opportunities to learn from one another. Mia’s “I wanna hear more” (Figure 4) exemplifies this move, suggesting an openness to reframing that invites members to share what they know. The cohort 3 students treated the problem as complex and authentic, and they occasionally

placed themselves into stakeholder roles. The students in cohorts 1 and 3 shared information, creating opportunities to learn interactionally about algae that they had not individually researched. They also learned how to share agency with the context in order to make decisions that meet stakeholder needs.

Understanding how students make use of problem context extends prior arguments for why providing sociotechnical problems matters (Jesiek et al., 2019; Law, 1987; Suchman, 2000). Our analysis shows that students in cohorts 1 and 3 shared their agency with context in order to frame the problem and evaluate the adequacy of their research. This analysis aligns with Schön's (1983) view of design as a conversation with materials, in which the students balanced their individual interests, the research, and the context to arrive at their decisions. In this case, the context seems to have been a necessary ingredient for framing agency, offering further insight into the nature of framing agency as distributed and shared between group members. Rather than showing clear and consistent ownership and direction, these students sometimes displayed lowest-agency talk in negotiating the design requirements and their knowledge of the problem. In particular, they used such talk to raise requirements in support of or against a proposed idea. These lowest-agency displays highlight how students contended with structural power. In contrast, the cohort 2 students frequently offloaded their agency onto the task and instructor. By treating the task as anchored to the instructional context, rather than related to a real-world setting, the decision-making displayed was not consequential and provided fewer opportunities for learning interactionally.

Teams from cohorts 1 and 3 commonly paired highest-agency talk with third-person references to research. The cohort 3 team also displayed ownership over the bounds of their understanding and used high agency in explaining their choices over which algae to research. Perhaps the cohort 1 team did not display such ownership over choices because they worked on a simpler problem, which provided an endemic limitation on their choices. In contrast, the cohort 2 team used highest-agency talk for multiple purposes, but seldom referenced papers; commonly, they displayed highest-agency as they shared their perceptions about the task, such as whether they should have focused on species or class, and how to operationalize criteria. While one might anticipate that their focus on completing the task as given to them might have led them to prioritize the content and make more reference to papers, we did not observe them referencing papers much. These differences in the targets of students' agency shed light on their perceptions about the authenticity of the problem and their roles in framing it. The micro participant structures in cohort 1 and 3 team suggests

iterative and analytic use of resources, as students commonly offered detailed explanations, noted the bounds of their understanding, and sought additional information during class. Conversely, students in cohort 2 commonly noted gaps in their notes and did not seek to fill those gaps during the session, even though they had explicitly mentioned that they should.

Our results also suggest implications for ways to use the construct of framing agency as a potential diagnostic indicator in navigating the assistance dilemma (Koedinger & Aleven, 2007) in PBL and PjBL classrooms, especially those that employ ill-structured problem framing and solving. Perhaps the cohort 2 team struggled to treat the problem as authentic, situating their roles as students finding answers efficiently due to a preponderance of past engagement with such problems (Barlow & Brown, 2020). Indeed, research suggests that repeated experiences with well-structured, decontextualized problems tend to pre-figure students' expectations (Kirn & Benson, 2018). By considering the differences across task and participant structures, we can identify possible ways to disrupt a preponderance of prior participation in well-structured problem-solving experiences.

We conjecture that the breadth and anticipated sameness of exploring every aspect may have both hindered positive interdependence and eroded some of the authenticity of the project for the cohort 2 students. That sameness, common to much of classroom experiences in which all students undertake the same tasks, is expected to produce the same result to the same problem. This pattern of sameness is identifiable in how cohort 2 students treated the pre-parley in class activity. Intended to be a generative sharing opportunity, cohort 2 students binned algae into types (e.g., green, red, brown) and affirmed the adequacy of their research based on finding at least one strain of each type. This activity built a false sense of adequacy of their research and may have situated the task as more classroom-bound and instructor-controlled. In contrast, the cohort 3 students critically evaluated the adequacy of their research by comparing possible criteria in their pre-parley activity, in turn preparing them to negotiate expected, endemic differences within their team due to their topical roles (i.e., growth, harvest, extraction). This focus helps us recognize that the commonplace critique of PBL and PjBL classrooms—"What if they don't learn the same things?"—may covertly sabotage opportunities for engaged learning within ill-structured problem framing. We argue that PBL and PjBL classrooms might treat difference as endemic and even normative, and that instructors can instigate expectations of difference via classical jigsaw approaches (Aronson, 1978) or by forming multidisciplinary teams (Imafuku et al., 2014). In this way, differences can become resources in ill-structured problem work that students can exercise their

framing agency upon. We thus argue that focusing on the kinds of task and macro participant structures that promote framing agency responds to calls for alternatives to directive scaffolding (Roll et al., 2018). Specifically, our results suggest several ways these structures can contribute to the development of framing agency in ill-structured PBL and PjBL: First, designed and endemic differences can be explicitly positioned as a resource. For instance, when instructors use macro structures that involve different roles, they can make clear in their instructions, examples, and assessments that they do not expect all students to know the same specific information, even when they hold expectations that students will learn to use information in the same ways. Likewise, instructors can share examples of how students' experiences can be useful in understanding authentic problems and evaluating tentative solutions. As an example, in our related work, we gave examples of how students from rural communities were able to use their first-hand knowledge to help their teams generate more feasible solutions (Gomez & Svihla, 2018). Second, task structures, like the process of determining criteria and using a decision matrix to guide choices, may be more potent when students recognize differences as a resource, rather than using the task as a way to check accuracy. Third, the utility of such task structures for fostering framing agency may depend also on sociotechnical context (Jesiek et al., 2019; Law, 1987; Suchman, 2000); rather than rendering problems unwieldy, we argue that sociotechnical context provides numerous perspectives for students to consider as they work to frame ill-structured problems. Fourth, and perhaps apparent from the prior three, these structures interrelate. The teams in cohorts 2 and 3 were provided the same task structures, yet the ensuing micro participant structures were quite different. We therefore advocate for approaches that consider these structures in tandem, as complexly related. Indeed, the changes made from cohort 1 to 2, in response to students' requests to experience all of the aspects, contributed to fewer and more diminished learning opportunities.

Finally, our results address a noted gap; undergraduate students report higher engagement in courses that use PBL, but they also report limited use of PBL in courses like ours—namely, lower-division courses with more than 50 students enrolled (Ahlfeldt et al., 2005). Our results showcase the depth of exchange possible when combining an authentic problem, a complex task, and realistic participant structures that promote positive interdependence. Rather than reserving such experiences as capstones, we argue that students need early and repeated engagement with such problems in order to develop problem framing skills needed to contend with ill-structured problems.

Conclusions

Given that the cohort 1 problem—choosing between two growing options—was simpler, one might logically expect the teams from cohorts 2 and 3, who were tasked with researching many algal strains and choosing one or more, to be similar in their discourse. Yet, we found the teams in cohort 1 and cohort 3 both displayed framing agency, whereas the team in cohort 2 did not. Instead, the team in cohort 2 left agency with the instructor and task, treating their role as efficiently finding accurate answers to a school-bound problem. Their discussion left little space for them to learn from one another interactionally. In contrast, the other teams treated the problem as authentic, anchored to a context outside the classroom, and used this situatedness to inform their problem framing, sharing their agency with the problem context and envisioned stakeholders. Their efforts to frame the problem provided opportunities for them to learn about the problem from one another, while also learning to frame ill-structured problems and, in the case of the cohort 3 team, exploring the kinds of designers they wanted to be. Collectively, our analysis suggests that the authenticity of the problem was diminished when students faced the more complex task (i.e., choosing algal strains) paired with a participant structure (i.e., cross-team comparisons of algae strains) that prompted a focus on accuracy over exploration.

Our purpose was not to evaluate the entire instructional design, and thus, we cannot draw conclusions here about the role that different forms of agency might have on longer term engagement and learning in PjBL. While our approach afforded the opportunity to closely examine students' interactional patterns during in class activities, limitations of our approach mean we cannot generalize our inferences. Future studies could address this gap by analyzing data from more of the teams, resulting in stronger backing for linking specific designs to specific behaviors. For instance, in our related work, we developed and tested a survey that measures framing agency in relation to specific course activities (Svihla et al., 2020; Wilson-Fetrow et al., 2023); future studies can use this survey to evaluate variability across teams and compare the impact of different participant structures. Additionally, many subtle features of agency in discourse are not captured in our stage one and two analyses; as a result of our close focus on subjects and verbs, we may have missed other patterns. Secondary analysis by another team, following more traditional discourse analysis methods, could resolve this issue. Finally, our particular context—an engineering department in a Hispanic-serving institution engaged in a department-wide effort to reform instruction to better serve

minoritized students, with data collected prior to the start of the COVID-19 pandemic—situates and shapes the transferability of findings.

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