BUILDING INDIVIDUAL ACCOUNTABILITY THROUGH CONSENSUS

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One of the difficulties faculty face is that because design challenges are open-ended, it can be difficult to predict directions students will take. As a result, faculty who teach core chemical engineering courses often focus on problem sets. We present a new pedagogical strategy that supports students to learn from each other and build consensus on design decisions. In turn, this helps make guiding students to connect core content to the design challenge more manageable for faculty.

PEDAGOGICAL THEORY

We sought to test a pedagogical theory that providing (1) a real-world design challenge threaded through a chemical process calculations course, (2) scaffolding related to decision making and (3) opportunities for peer-learning in a caring environment would support students to learn from each other and develop a sense of ownership over their learning.

Research shows that providing students with real-world design challenges supports them to develop applied understanding of core engineering concepts, in addition to enhancing the retention of students from groups underrepresented in engineering.[1,2] For instance, brief design challenges in a first-year chemical engineering laboratory course engaged students in a design process of active learning from simulations to develop initial understanding, planning their own designs using simulations before building functional prototypes, and evaluating their designs by collecting and analyzing data.[3] One such design challenge involved building a photobioreactor. Students responded positively to the course, viewing it as supporting their learning and contributing to their intent to persist in chemical engineering. Design challenges have also been used throughout core chemical engineering courses.[4]

While design challenges provide interesting context for applying core concepts, research on guiding the learning process and supporting students to make productive design decisions remains somewhat limited. Researchers have long argued for pedagogical approaches to teaching chemical engineering that are backed by research on learning, such as balancing concrete and abstract content and providing active and cooperative learning experiences.[5]

Making authentic decisions in design projects can lead to enhanced sense of ownership over learning.[6] To support students to make decisions related to the design project, we created a scaffolded activity we call a parley session, which in our past research supported students to learn from one another.[7] Past research on scaffolding suggests that student learning can be deepened and extended with the help of supports—scaffolds—that walk students through challenging tasks.[8,9] For instance, effective scaffolding of collaborative design projects can help team members develop shared understanding of the problem and engage them in productive discussion.[9]

We sought to scaffold students' design decision making within teams. We wanted students to individually research numerous aspects of the design problem, yet develop consensus as a team by comparing information from reputable sources. When making decisions, engineers commonly use tools such as Pugh charts and decision matrices, and these have been used successfully to support engineering students

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to make design decisions.[10] Research on decision making and argumentation in science classrooms has demonstrated that having students come to consensus better supports their conceptual understanding, compared to having them try to persuade each other.[11] This is in part because when trying to persuade one another, students tend to explore the problem space shallowly.[12]

Working in teams provides students with more opportunities to make sense of the information they are learning.[5],[13] The social aspect encourages them to come to class prepared to engage with the content and with one another. However, past research has clarified that students display different types of interaction. Conversation analysis of student talk while solving homework problems in a sophomore chemical engineering course revealed two common interaction patterns: transfer-of-knowledge and collaborative sequences.[14] In the former type of conversations, students took on roles of traditional teacher and students, with one student directing the conversation and explaining their reasoning to others, who predominantly listened or asked for clarifications. In the latter type of conversations, students tended to contribute on relatively equal footing, with overlapping talk and exploration of ideas. Overall, most of the conversations recorded were categorized as transfer-of-knowledge.[14] While this demonstrates that students had abundant opportunities to learn from a peer, some almost exclusively occupied the role of student, which frustrated their teammates. Based on this finding, the researchers emphasized the importance of the instructor in managing and modeling productive interactions.

The interactions students have with the instructor affect how they frame the instructional opportunities and feedback they are offered; not showing students respect can render other curricular innovations ineffective.[5] Noddings introduced the idea of *care ethics* as a means to characterize how instructors can use productive relationships to support learning.[15] Because they occupy positions of relative power, instructors should be attentive to students, meaning they should consider the contextual and actual, rather than assumed, needs. In this way, students' needs should be addressed empathetically and with learning in mind, by listening to their ideas. This is instrumental in classroom settings that aim to employ effective active and cooperative learning.

METHODS

Study Design and Research Purpose

We conducted two iterations of design-based research (DBR).[16,17] In this approach, researchers repeatedly test and refine a pedagogical theory about how to support learning by instantiating the theory in an instructional design and testing it under real world conditions through specific conjectures about how it should function. Prior analysis of the first version of parley sessions established that students found them to be engaging and that students learned from each other.[7] In this study, we compare two consecutive versions of an algae biofuel design challenge threaded through a material and energy balances course. There was no reduction in the core content of the course to accommodate the design challenge, which leveraged six recitation periods from a total of fourteen for in-class activities. The out-of-class time commitment for students was not increased as the design deliverables were integrated into homeworks by replacing existing questions with design challenge-related work. We scaffolded students' designing using decision matrices and created opportunities for peer-learning in a caring environment. We aimed to support students to learn from each other and develop a sense of ownership over their learning.

In this paper, we report on two iterations, particularly focusing on how the parley sessions supported student engagement and learning. We sought to understand how parley sessions might foster individual accountability, peer interaction, and conceptual learning. We conjectured that providing and refining the decision matrix scaffold and parley session would support students to conduct independent research, identify appropriate criteria, bring together and value diverse ideas, and negotiate towards consensus. We conjectured that the caring environment fostered by the instructor would support students to participate in collaborative sequences in their negotiations. Finally, we conjectured that collectively, this design should create opportunities for students to feel a sense of ownership over their learning. We therefore investigated the following research questions:

1. *How and to what extent did parleys support students to identify, use, and display ownership over ideas from relevant and reputable sources?*
2. *How and to what extent did parley sessions support students to learn from one another in a caring environment?*

Participants, Setting and Study Materials

The participants are chemical engineering sophomores from two iterations of a material and energy balances course taught in 2016 (n=66) and 2017 (n=70) at a Hispanic-serving research university in the southwestern US. We used the research-based CATME tool to form teams (https://info.catme.org/);[18] we used the preset values to ensure that minorities would not be isolated on teams. The class is taught in a learning studio—a room outfitted with 13 round tables, each with an LCD screen that can project content to the two main projector screens. There are also 13 whiteboards and huddle boards used for student demonstrations.

The course includes a semester-long design challenge as well as traditional content including lectures, quizzes, and exams (Table 1, for access to course materials: https://canvas.instructure.com/enroll/MKGRH8). An algae-based design challenge for biofuel production was implemented to give students a grand, unsolved, real-world engineering problem that related to course learning outcomes. It is woven throughout the course utilizing recitation periods for collaborative sessions. Students have access to challenge materials including a prompt, kickoff video, templates for both technical reports and collaborative sessions as well as how-to-guides for navigating deliverables. In this study, we specifically focus on collaborative sessions we call parleys.

A parley session supports students to bring together their individual research and decisions to come to consensus as a group. Students made individual and collective decisions within every technical phase (growth, harvest and extraction) of the algae biofuel design challenge.

Prior to each parley session, students complete a worksheet out of class that scaffolds them to do research and make individual decisions about a key design decision. For example, the students were scaffolded to individually identify the pros and cons of at least three genera and based on this, select one genus as their individual choice in preparation for the parley session. During the parley session, students bring hard copies of their pre-parley worksheets to consolidate together in their teams. The consolidation process involves deciding on criteria to compare their individual choices, weighting each criterion to determine its level of importance, scoring each possible option to rank choices, and making a final group selection. The process uses a decision matrix tool (Table 2).

TABLE 1
Threading of two iterations of the algae biofuel design challenge through the course.
In iteration 1, homework was not connected to the design challenge. In iteration 2, all homework included design challenge applications. Some iteration 1 deliverables were folded into iteration 2 homework.

Topics	Week	Iteration 1: 2016	Iteration 2: 2017	Homework due
Chemistry review	1	Design challenge video launch		
	2	Parley: growth method		
Single phase systems-real gas Multiphase systems	3	Deliverable: Project proposal	Deliverable: Growth phase proposal PreParley: Strain	X
	4			
Material Balances	5	Deliverable: Progress check on decisions		X
	6		Deliverable: Harvest phase technical report PreParley: Harvest	
	7	Deliverable: Annotated Bibliography; *process calculations. Jigsaw	Parley: Harvest	X
Exam 1	8			
Material Balances continued	9	Parley: Location		
	10			
Energy Balances	11	Deliverable: Phase worksheets		X
	12		Deliverable Extraction technical report PreParley: Extraction	
	13	Deliverable: *Process Description with flowchart	Parley: Extraction	X
	14			
Exam 2	15	Deliverable: Team presentations		X
Transient processes	16			
Exam 3	17			

TABLE 2
Sample abbreviated decision matrix from the algal strain parley session.
The full matrix includes lines for each team member to enter their name and choice, and room for at least 5 criteria.

Recap your individual decisions in the following table

Name	Choice

With your team, assemble a decision matrix to come to a consensus on your final choice.

		Strain 1:		Strain 2:		Strain 3:		Strain 4:	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Total									
				Best option:					
				Team choice:					

The instructor sought to build informal relationships with students by walking around, observing and engaging students during the parley and lecture sessions. She showed interest in their lives outside of class, recognizing that challenges at home can impact in-class participation. She also built a sense of community. For instance, following an exam, she encouraged a sense of competence and ownership by asking students who got an exam question correct to stand, then asked for a volunteer to share their strategies and solutions with the class. This nurtured a respectful environment in which students could see their diverse peers as a source of knowledge. This aligns with research showing that faculty explicitly modeling the ethic of care can provide motivation for students to care about interactions with stakeholders and the environment.[19]

Design based research iterations and refinements

Following DBR methodology, based on our analysis of the first iteration, we made several changes for the second iteration. First, using the algae biofuel production process as context, there was better integration of the design challenge and all of the homework assignments. Students from the first iteration co-designed these homework problems. We did not include such problems on the exams.

Second, we left out the option for students to choose between open pond and bioreactor because all but one team chose bioreactor. Because most students made the same choice, this left little for them to negotiate within their teams, making it a poor target for using the decision matrix. Decisions on which there are multiple points of view or disagreements are most appropriate for parleys. Instead, we made using a bioreactor a design requirement. As a result, the first parley in iteration 2 focused on selecting an algae genus.

Third, we changed the structure of the teams and, therefore, the forms of peer learning. In the first iteration, we divided the class into three large production-phase teams: one focused on growth, one on harvest, and one on extraction. Each team was then divided into smaller subteams of three students. During parley sessions, students brought their previously-conducted individual research and decisions together and came to consensus within their subteam, then within their larger production phase team, and finally as a whole class. The parley sessions focused on the growing system, algae genus and source of carbon dioxide. Collectively, students in iteration 1 chose a combined flocculation and decanter centrifuge method for harvesting and a single-step oil technique for extraction. In iteration 2, based on student feedback from focus groups and end-of course evaluations, we omitted the large, production-phase teams. Instead, each team of 6-8 students investigated all phases. During parley sessions, students brought their previously-conducted individual research and came to consensus as a team, but did not come to consensus across teams. The parley sessions focused on algae genus, harvest method, and extraction method. Teams chose 7 different harvest methods (disc-stack centrifugation, sedimentation, flocculation, auto-flocculation, electro-flocculation, membrane filtration, and flotation) and 5 different extraction methods (ultrasonic assisted extraction, hexane solvent, sonication, bead beating and combined supercritical fluid and expeller press methods).

Fourth, because the students in iteration 2 were no longer focused on different production phases, we knew the traditional approach to a jigsaw would not work well, even if they had investigated different genera of algae. We experimented with a collaborative concept-mapping tool (mindmeister.com), but found it cumbersome for our purposes, which included having many students edit synchronously while sharing with other teams. We also noted that they needed support deciding which criteria were most important, and thus, we created pre-parley sessions focused on comparing criteria with members of other teams, including establishing relevant units where appropriate. This aligns to research on supporting engineering students to make decisions.[10]

Fifth, we made refinements to our scaffolding on worksheets. The worksheets scaffolded students to independently conduct research on various aspects of algae biofuel production, from growth, specific genera, harvesting, and extraction methods. In the original version, we did not specifically include a space for citations. While some teams referenced many reputable sources in the first iteration, a few teams did not, or did not use the references in their discussions. To aid them, we specifically prompted them to include their citations in the parley materials by including a space for them. We also provided a 6-page guidebook that included information on citing reputable sources, examples of citations, how to use a citation manager (i.e., Mendeley), and how to write an annotated bibliography.

DATA COLLECTION AND ANALYSIS

We video and audio recorded student conversations and interactions during the parley sessions. To analyze these data, we conducted conversation and interaction analysis,[20] including categorizing talk as transfer-of-knowledge or collaborative sequences.[14] We particularly attended to how students engaged in the parley sessions, and how the sessions fit within the project and course. We sought both confirming and disconfirming evidence for our conjectures.

We collected copies of student work and conducted open coding, building on a previously validated coding scheme (Table 3). We triangulated our analysis by comparing findings across researchers and data types.

TABLE 3
Scheme used to code criteria students listed for selecting an algae strain

Code	-1	0	1
Temperature	Not mentioned	Mentioned without elaboration *Ex: "Temperature"*	Mentioned with (specific) range, concerns about too hot or cold, or fluctuation *Ex: "Temperature range 15-25C"*
Growth	Not mentioned	Mentioned without elaboration *Ex: "Growth" "biomass"*	Mentioned with specific details, growth rate or biomass production rate *Ex: "Growth 24 hours per day"*
Light	Not mentioned	Mentioned without elaboration *Ex: "Light"*	Mentioned with specific or technical detail, or with range *Ex: "Damage resistant to synthetic light"*
Water source	Not mentioned	Mentioned without elaboration *Ex: "Wastewater"*	Mentioned with specific detail or source, possibly as source of nutrients *Ex: "Grown in dairy wastewater"*
Lipid Content	Not mentioned	Mentioned without elaboration *Ex: "Oil" "Lipid"*	Mentioned with specific or technical detail, or with range *Ex: "Lipid content per gram"*
Harvest	Not mentioned	Mentioned without elaboration *Ex: "Harvest"*	Mentioned with specific or technical details about harvesting *Ex: "Ease of harvesting"*
Extract	not mentioned	Mentioned without elaboration *Ex: "Extraction"*	Mentioned with specific or technical details about harvesting *Ex: "ease of extracting"*

In order to understand the impact of adding scaffolding for citing sources, we tabulated the number of citations students made across the worksheets. Each citation was counted and categorized into journal, book, website, or other (such as white paper or tech review). If multiple students cited the same source, each citation was counted.

We coded student work on the final parley session for each iteration. In iteration 1, students identified sources of CO_2, and in iteration 2 they considered extraction methods. In both cases we sought evidence that students learned from each other. Keeping in mind that students came up with criteria individually, we tallied how many students identified each criterion in their pre-parley work and compared this to the criteria they came to consensus on as a team. We conjectured that if students did not initially consider any particular criterion, the parley session would provide opportunities for them to learn about that criterion from peers. We triangulated this with analysis of conversations during parley sessions to see if students negotiated criteria and had opportunities to learn from one another.

RESULTS AND DISCUSSION

We present results related to our conjectures across the two iterations. Overall, we found that students discussed the research they found as well as negotiated the criteria relevant for making decisions. We present our results organized by our research questions.

RQ: How and to what extent did parleys support students to identify, use, and display ownership over ideas from relevant and reputable sources?

To answer this question, we include analysis of student work on parley materials showing that students investigated relevant and reputable sources, and that a refinement to our scaffolding better supported this. We share examples of both transfer-of-knowledge talk and collaborative sequence talk to highlight the range in conversations as students shared what they had learned with one another; in these sequences, we draw attention to how students did or did not display a sense of ownership over the ideas.

In iteration 1, our analysis showed that across 3 parley worksheets, students collectively made 31 citations to journals, 41 citations to websites, and 15 citations to other sources, such as white papers and tech reviews. Students cited these two websites most frequently: http://www.oilgae.com/algae/ and https://www.e-education.psu.edu/egee439/node/696 in their worksheets.

In iteration 2, we added specific prompts to the worksheets to encourage students to cite their sources. Our analysis showed that across 3 parley worksheets, students collectively made 392 citations to journal articles, 7 citation to books, 220 citations to websites, and 41 citation to other sources, such as white papers and tech reviews. For instance, books such as *Separation and Purification Technologies in Biorefineries* (Ramaswamy, 2013) and the *Handbook of Microalgal Culture: Biotechnology and Applied Phycology* (Richmond, 2007) were used by some of the students. This shows that our refined scaffolding supported students to locate a larger number of sources.[9]

In both iterations, students conducted individual research on algae genera prior to a parley session. In iteration 1, across the entire class, students investigated 8 algae genera, and the teams came to consensus on their decision to grow the chlorella genus during the parley session. In contrast, in iteration 2, students investigated 19 algae genera. The team decisions on algae genera were diverse, with a total of 7 genera selected including Chlorella, Thlassiosira, Scenedesmus, Ankistrodesmus, Porphyridium, and Botryococcus. Overall, students in the second iteration investigated a greater diversity of ideas. We infer that this may have been tied to the decision to have teams—but not the class as a whole—come to consensus, resulting in greater sense of ownership over their design ideas.

In both iterations, students made reference to their sources during parley sessions, including to relevant statistics and specific data during their conversations with their peers. In iteration 1, in just 30 minutes of the first parley session, the team we recorded made 14 different references to their resources. For instance, Mia made reference to a paper she read, "What I was reading is the lab – they're a lot more efficient at making the algae produce, so productivity is greater and faster" and later, in considering challenges to open systems, she referenced another reading, "One thing I read about the open systems is, it has a larger surface area to volume ratio which is really important for exposing algae to all the nutrients it requires, so and that was like, the big thing is it's like way more efficient." Students were actively engaged in these discussions; as evidence, at one point, when the instructor asked them to move on the next part of the activity, Josiah said, "Shh. Let's just keep discussing." And they did continue to discuss the pros and cons of open ponds and bioreactors, referencing papers they had read as they did so (Figure 1).

First, we note that students made references to sources they read, and in doing so, they argued from evidence. Because students prepared their ideas and arguments prior to class, we anticipated finding transfer-of-knowledge sequences, in which one student took on the teacher role and others took on learner roles. We do see some sequences like this above, especially when Josiah talked, but unlike the findings from past work,[14] we did not see students habitually occupy either role. For instance, above, Mia positioned herself as a learner who wants to "hear more" but elsewhere, Mia positioned herself as a teacher, (see Transcript 2). However, even where Josiah occupied a teacher role, he exhibited some uncertainty about the terms, and this invited other students to engage in sensemaking with him, resulting in more collaborative sequences than were described elsewhere.[14] We argue that the parley session, which scaffolded students to do independent research prior to class but then negotiate ideas together, supported this kind of collaborative sensemaking.

Elena was hesitant as she explained her ideas about the cons for a closed system, but she displayed ownership over them by beginning with "I think" and envisioning herself in the scenario (lines 37-38). Josiah displayed ownership and less hesitation when he said "I got a bunch" despite later uncertainty about technical terms, though this did not stop him from engaging with the ideas. Mia displayed ownership over her role as a learner, citing that she wanted to hear more, not that the task required more input. Similar to past research, the parley sessions supported students to display a sense of ownership over their ideas and negotiations.[6]

RQ: How and to what extent did parley sessions support students to learn from one another in a caring environment?

To answer this question, we include analysis of student work on parley materials showing that students brought diverse ideas from their independent research and negotiated these as they came to consensus on criteria and decisions. We share examples of collaborative sequence talk that characterized their discussions. Finally, we share an example of care ethics displayed by students.

Mia: Okay. 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
[*No one responds to Josiah*]
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 if // both of 'em 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 photobio-reactors are small. Ish. Like the size of like //
Mia: //Yeah//
Josiah: //one building. You know, they're not 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 O_2 from the systems.
Mia: Okay.
Josiah: So that, when that builds up then the plant no longer uses CO_2 to make what it needs to make, and it just uses the O_2 to do photorespiration.
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.

Figure 1. *Students from iteration 1 discuss pros and cons of open ponds and bioreactors. Line numbering begins at 30 to depict a conversation already in progress. // indicates overlapping talk. Punctuation indicates tone. (.) indicates a noticeable pause. :: indicates a drawn out sound. [ ] provides context or additional information*

To find evidence of team members negotiating and learning from one another, we posited that students would propose different criteria on their individually completed pre-parley worksheets, and that during parley sessions, they would negotiate which criteria mattered most in making their decisions. We compared the criteria students individually proposed to the team criteria they negotiated. Specifically, we analyzed student work from the iteration

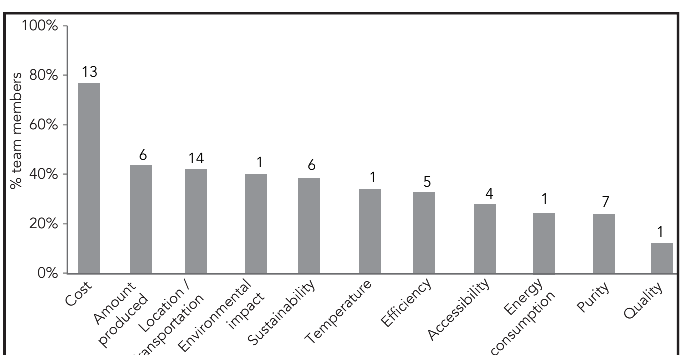

Figure 2. *Percent of members on average per team in iteration 1 who selected each criterion when choosing the source of carbon dioxide. Numbers over bars represent the number of teams that mentioned each criterion.*

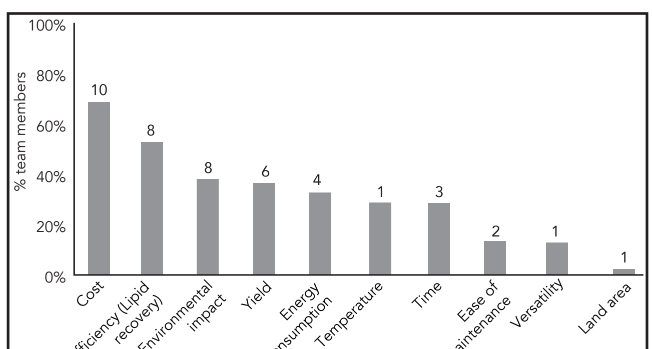

Figure 3. *Percent of members on average per team in iteration 2 who selected each criterion when choosing a method of extraction. Numbers over bars represent the number of teams that mentioned each criterion.*

1 parley session focused on choosing the source of carbon dioxide and the iteration 2 parley focused on choosing a method of extraction.

In iteration 1, across all teams and criteria, on average each criterion was mentioned by 43% of team members. More specifically, 14 of 15 teams mentioned transportation/location and 13 mentioned cost. Other criteria were mentioned by fewer teams (Figure 2).

In iteration 2, across all teams and criteria, on average each criterion was mentioned by 51% of team members. More specifically, 10 of 10 teams mentioned cost, 8 mentioned efficiency and 8 mentioned environmental impact. Other criteria were mentioned by fewer teams (Figure 3). As an example, when filling out the pre-parley sheet (Table 4, similar to Table 2), students in team #4 proposed four different methods of extraction and came to consensus on five criteria—cost, percent yield, environmental impact, efficiency, and speed—to arrive at their team choice.

TABLE 4
Decision matrix for solvent selection
At the beginning of the parley session on extraction, three students selected hexane solvent, three selected supercritical fluid, one selected electro-poration, and one selected the Folch method. Teams were given the instruction: With your team, assemble a decision matrix to come to a consensus on your final choice. By agreeing on criteria, they were able to come to consensus and select hexane solvent.

Scale: 0-3, where 3 is Best and 0 is Poor

		Choice 1: Hexane Solvent		**Choice 2:** Supercritical Fluid		**Choice 3:** Electro-Poration		**Choice 4:** Folch Method	
Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Cost	0.2	3	0.6	1	0.2	2	0.4	2	0.4
% Yield	0.3	3	0.9	3	0.9	3	0.9	2	0.6
Environmental Impact	0.15	2	0.3	3	0.45	1	0.15	2	0.3
Effciency	0.2	2	0.4	3	0.6	2	0.4	1	0.2
Speed	0.15	1	0.15	1	0.15	2	0.3	3	0.45
Total			2.35		2.3		2.15		1.95
				Best option:		[students left blank]			
				Team choice:		Hexane Solvent Method			

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. The winter time, means that the temperature will get better and better, faster.
Derek:	What does an incline pond look like? //
Mia:	// *[directing her talk to Elena]* So I feel like the biggest issue is it's like expensive. I think that's the biggest thing oh and also you would need someone with the expertise to take care of it and take readings and stuff like that. //
Josiah:	Well, it's just a flat pond.
Derek:	Oh, at the bottom. I thought you were talking about the pond is like on a hill. First of all, how's that gonna work?
Josiah:	It's sort of like that. And then your culture depth is 3.5 centimeters. That's all. It makes it easier to harvest off of that, too.
Derek:	But then you also have to also take into consideration the evaporative losses in the water.
Josiah:	//That's the con that I put on the open like if it's an open pond we're gonna lose all the CO_2 in all the water, so that's gonna be the most expensive operating cost, probably after start up.//
Mia:	//*[Mia and Elena continue to discuss]* One thing I read about the open systems is it has a larger surface area to volume ratio which is really important for exposing algae to all the nutrients it requires so and that was like big thing is it's like way more efficient.//

***Figure 4.** A collaborative sequence emerged as students from iteration 1 negotiated pros and cons related to open ponds and bioreactors. This interaction occurred shortly before that in Transcript 1. Note that punctuation indicates tone.*

The diversity of criteria within teams suggests that they conducted their pre-parley research individually. This aligns to our observations that students appreciated the divide-and-conquer approach to gathering information before bringing it together as a team. Thus, in iteration 1, more than half, and in iteration 2, almost half of the members brought diverse ideas and had opportunities to learn from one another, as evidenced by the fact that they agreed on criteria that some had not originally considered. However, one could conjecture that instead of suggesting opportunities for learning from peers, some students simply accepted a peer's choices. We therefore turn to our analysis of conversations from parley sessions.

If students primarily accepted a peer's choices, we would expect to see transfer-of-knowledge talk dominating the discussion. Instead, based on our analysis, we primarily observed collaborative sequences (Figure 4), sometimes starting from brief transfer-of-knowledge talk but then shifting quickly into a collaborative sequence. For instance, in the first parley session, we identified 29 different sequences of talk, and coded 5 (17%) as transfer-of-knowledge, 5 (17%) as starting as transfer-of- knowledge but quickly shifting to collaborative, and 19 (66%) as collaborative. We caution that interpreting these numbers is difficult, because this would require an "analytically defensible notion of the denominator,"[21] which in this case would involve knowing how much collaborative talk is sufficient, and for what outcomes. However, we can compare this to rates reported elsewhere,[14] in which only 31% were collaborative, except in groups comprising only women, in which up to 50% were collaborative. Others have found that this type of collaborative talk is useful in making collective decisions, and that "rather than engaging the point of contention until a decision was reached, they circled around disputed topics, making several different points without focusing the group on the points of contention."[22] This is very similar to the collaborative sequences in our data. Collaborative sequences can predict knowledge acquisition,[23] which suggests that our students did have opportunities to learn from one another. This aligns to findings elsewhere that having students to come to consensus supports learning better than encouraging them to persuade their peers of the accuracy of their ideas.[11] As we see from the parley conversations, the collaborative sequences led to deep exploration, similar to findings elsewhere.[12]

Across this parley session, we observed students shifting between conversations, eager to share their knowledge with one another, but then coming back together as larger groups. For instance, Mia explained the pros and cons she identified to Elena while Josiah and Derek discussed other pros and cons. Here, we see Mia occupying the role of teacher, explaining her ideas to Elena, while Josiah and Derek engage in a collaborative sequence prompted by Derek's query about an incline pond.

Elijah:	So //
Samantha:	//Ok so
Elijah:	For the content I'd say maybe .3 or .4 given how we still, depending on how many parameters we have.
Edina:	We need to discuss this as a class. We can't do this as a group. You can't just tell me. We gotta talk to everybody.
Elijah:	I know. I'm just trying to give suggestions because nobody's listening and it's really frustrating but (.)
Kim:	OK you guys let's all come together (.) Right. So we have all the methods and stuff and our weighting. So what's going to be our weight for high-lipid content.
Elijah:	Uhhh. I'd say
Andrew:	I'd say so too. I feel like I should say so too.
Elijah:	Let's say .3. Maybe// Maybe .4.
Kim:	//Everybody? We good on .3? .3 or .4?
Samantha:	What's the highest?
Elijah:	Either //
Andrew:	//1
Edina:	1
Elijah:	Depending on if we have more items to add or not.
Kim:	The sum has to be 1, depending on the weights. So this has to be// 1
Andrew:	//So I'd say it's most—So do you guys think .4 since that's our most important
Samantha:	I think .4
Kim:	Ok.
Andrew:	I agree with that.
	[As they continue to decide on weightings, they check in on member agreement, and each member voices their agreement]
Samantha:	Cool. Now we're good.//
Elijah:	//Ok.// Good enough.
Samantha:	//Awesome!
Andrew:	//Good.

Figure 5. *A team from iteration 2 exhibits the ethic of care as they negotiate weightings of criteria in their decision matrix.*

In the next vignette, from the first parley session in iteration 2, team members had just decided on criteria for selecting an algae genus (Figure 5). During their negotiations, Elijah appeared to feel left out of the discussion, and his frustration became apparent as the team began to negotiate what the weights should be for each criterion in their decision matrix.

Kim exhibited care ethics and drew Elijah back into the conversation, resulting in a collaborative sequence of talk. Kim's move to bring the group together not only displayed care ethics, it also created an opportunity for peer learning through a collaborative sequence of conversation. This aligns to past research on the ethics of care,[15] and provides an example of how an instructor's modeling of care was adopted by students and supported engineering learning. While the ethic of care has been studied in professional fields such as medicine, it is less studied in engineering. Because of the potential benefits, this is a fruitful area for future study.

Across these conversations in parley sessions, the students were engaged and negotiated their understanding with each other, thus supporting our assertion that parley sessions provided opportunities for peer learning and that students exhibited care ethics with each other.

Limitations

Although our parley sessions were successful, we recognize that the research was conducted in an uncommon setting—a Hispanic-serving, very high research institution, taking advantage of our institution's learning studio facilities, etc. In doing design-based research, we acknowledge that myriad contextual factors can influence how well a particular curricular innovation works. Although our study design does not allow us to generalize, it does allow us to attend to transferability—the aspects that seem central to its effectiveness and where it might be brittle when tried in a new setting. It was this focus that drew our attention to the importance of the instructor creating a caring environment. Because this was an emergent and not planned aspect, our methods were limited in their ability to provide insight into how prevalent students' displays of care ethics were; future research is needed to systematically identify such instances.

The focus of this study was to understand the role of parley sessions in supporting learning through design. This research was conducted as part of on-going broader curricular reform efforts, and these related efforts may have subtly shaped students' participation. Our purpose was not to gauge the effectiveness of using design challenges versus lecture, and our methods in this study do not permit us to answer questions about long-term impacts, though our future research will track the overall impact of changes. Likewise, our focus was not on the effects of gender in teams. Because scholars have argued that gender is an omnirelevant identity and as such, can never be discounted, further research could investigate gender effects.

CONCLUSION

Overall, we found support for our pedagogical theory that parley sessions can serve as a key peer learning strategy as part of a real-world design challenge. Based on analysis of both student work and conversations, in both iterations, students found and used relevant information from various types of sources. The refined scaffolding in the second iteration better supported students to document their research. They displayed ownership of their ideas even when they were still uncertain. This uncertainty led to shifts from transfer-of-knowledge talk to collaborative sequences. The parley sessions provided opportunities for students to negotiate ideas and learn from peers. Students displayed care ethics with peers and this enhanced collaborative sequences. This was reflected in their work where students brought diverse ideas together.

Parley sessions, in addition to supporting students to learn from peers, make it easier for faculty to guide students to connect core content to design challenges. By scaffolding students to investigate diverse ideas and criteria related to key decisions in a design challenge, the problem space is reduced somewhat, resulting in more manageable and productive learning of core content. Without this, students might focus on aspects that lack connection to core content or are too difficult given where they are in the chemical engineering program.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. EEC #1623105. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We would also like to acknowledge the contribution of members of the Advanced Qualitative Research Methods course who contributed to transcription and analysis efforts.

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