RURALITY AS AN ASSET FOR INCLUSIVE TEACHING
in Chemical Engineering

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One of the professional duties of an engineer is to "hold paramount the safety, health, and welfare of the public,"[1] and this is reinforced in the ABET student outcomes. Despite this, serious ethics violations by engineers have endangered people—often from vulnerable populations, such as in the case of the Flint water crisis.

We argue that chemical engineering programs can do more to support the development of professional engineering ethics, and further, that diversity can be a resource in this process. In this paper, we provide an example of a pedagogical strategy that aims to enhance diversity in early chemical engineering coursework. In our example, we focus on rurality—the notion that rural communities differ from one another and that rural community members bring relevant expertise from their rural experience[2]—and show how rurality can serve as a resource in learning through design challenges. Approximately one quarter of New Mexicans hail from rural communities. Rural students in our state are disproportionately from economically disadvantaged communities, with 30-45% of rural children growing up in poverty. As a minority-majority state, our rural students are underrepresented in engineering and also disproportionately likely to be the first in their families to attend college. Although our institution does not release data on our rural student persistence, elsewhere, students from any of these groups are less likely to enroll in and graduate from STEM programs.[3] People from rural communities are often framed, especially in popular media, as backward or unsophisticated. We counter this deficit notion, inspired by the passion we have observed in our rural students who often want to give back to their communities. We sought to develop and test a pedagogical strategy that could leverage this passion. We were guided by research on community-engaged and service learning, culturally responsive teaching (CRT), and design learning, particularly related to the tenets of project-based learning.

Community-engaged and service learning motivate students and support applied understanding

Students enter the classroom with different cultures and needs. Community-engaged and service learning help to create an integrated student-centered environment, which

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The theory we sought to test is as follows: Design challenges that are open-ended, contextual, current, and relevant—and that provide students with opportunities to pursue their own solutions to problems that reflect the work of engineers—support learning

contributes to student engagement and motivation. By helping to instill a sense of ownership in the learning process, service learning engages students who are otherwise alienated by the impersonal atmosphere of the university classroom.[4] In engineering, service learning allows students to use their technical knowledge to address and meet community needs,[4] promoting deeper understanding of course content as well as civic responsibility; students learn to value "the social dimension of the design process" and become adept at understanding "community members' needs coupled with the development of an appropriate engineering solution."[5]

While the benefits of community-engaged and service learning projects are clear,[4] they are notoriously challenging to implement—especially in high-enrollment courses, because of the effort required to organize, maintain, and facilitate relationships with community partners. We therefore sought to create a pedagogical strategy that was inspired by community-engaged and service learning, providing meaningful learning opportunities even in high-enrollment courses.

Culturally responsive teaching (CRT) supports empathetic design education

Our approach builds on the notion of CRT,[6] an inclusive, student-centered pedagogy that values the experiences and cultures of students. Such approaches treat students' experiences as a foundation on which to build future learning.[6] Past research on indigenous and rural Latinx (an inclusive term that eschews gender binaries inherent in Latino/a/@) youth has shown the benefit of CRT, including in engineering.[7] CRT aligns to teaching through design because both approaches treat human experiences as relevant to understanding and solving problems. Designers develop empathy and seek to understand multiple perspectives on a problem to ensure their solutions address a range of needs. Likewise, as teachers, if we value the diverse experiences and perspectives our students have, as CRT suggests, we are likelier to meet their learning needs. For instance, in one study, researchers first identified the assets students brought, then connected these to community-engaged design projects.[7] Such approaches make engineering seem more relevant and more connected to students' lives[8] and have supported low-income, first-generation college attendees, by first identifying their strengths—such as the ability to define and solve problems related to limited financial means and having empathy for marginalized communities—and connecting these to the work of engineers.[9]

Tenets of project-based learning support diverse students to learn

Project-based learning is commonly used in engineering, generally as design projects,[10] engaging students in responding to authentic challenges that have multiple possible satisficing solutions. While instructors provide resources and scaffolding, much of the learning is self-directed.[11] Project-based learning provides opportunities to develop professional and industry skills,[12] to refine students' project management and creative problem-solving skills, and to apply concepts.[13] Broadly, research across settings has shown that project-based learning better supports coherent understanding and retention, compared to traditional approaches.[14] Providing authentic problems to solve—although they can be difficult to manage—supports student learning[15] because such problems have meaning beyond the classroom walls, allowing students to make connections as they integrate concepts and practices.[11] Because students tend to prefer authentic problems, they commit more effort and time to them,[16] which in turn supports learning. Projects support students by creating a need to know, motivating them to learn with understanding and to persist when faced with challenges.[12,17,18] By using problems that were current, contextual, and relevant, our pedagogical strategy created this sense of authenticity in design challenges.

PURPOSE

Our purpose in this paper is to illustrate—using rurality as an example—how students' diversity can serve as a resource for solving design challenges. Design problems are contextual. Our approach positions students who have first-hand knowledge of those specific contexts—including from everyday experiences—as having relevant expertise.

METHODS

Research questions and study design

We used a research method called design-based research, a method popularized in the learning sciences that allows researchers to instantiate a theory of learning into a design for learning and systematically test it in real-world conditions .[19] Such theories are contextual conjectures about how to support learning in specific conditions.[20] The theory we sought to test is as follows:

> *Design challenges that are open-ended, contextual, current, and relevant—and that provide students with opportunities to pursue their own solutions to problems that reflect the work of engineers—support learning; in particular, design challenges that build on students' experiences, such as their first-hand knowledge of rural life and rural concerns, provide an opportunity for students to learn from each other's experience as they consider the viability of their designs.*

TABLE 1
Comparison between our rural and non-rural students in the first-year and sophomore-level courses.

	Rural students (n=14)	Urban & suburban students (n=78)
Growing up, spoke a language other than English at home	21%	10%
Growing up, spoke English and another language at home	21%	26%
Growing up, spoke English as the only language at home	57%	64%
First-generation college attendee	43%	23%
Underrepresented group (Hispanic/Latinx/Native American/ African American/Pacific Islander)	43%	21%
Growing up, had a friend or family member who was an engineer	50%	71%

Broadly, we wondered how design challenges that address rural concerns might enhance rural students' learning and expand their urban peers' understanding. We explored this through two cases in early chemical engineering coursework using qualitative methods. We were guided by the following research questions, explored in the context of design challenges that include a rural, community-based goal or context:

1. *How do student teams justify their design solutions to an antimicrobial design challenge compared to a rural clean water challenge in a freshman-level course?*
2. *How do students enrolled in a core, sophomore-level course leverage rural knowledge as they design an algal biofuel plant for a rural community?*

Setting and participants

We collected data in two early chemical engineering courses: a 1-credit first-year course that is designed to introduce students to the degree program, scope of career options, and type of work chemical engineers do; and a sophomore-level core-content course on chemical process calculations. The first-year course met in a traditional lecture hall. The sophomore course met in a learning studio—a room with large round tables, whiteboards and screens on all sides of the room, and a central podium. In both courses, students worked in teams of three to five and were given assignments to scaffold their progress. During the first week of the class we sought informed consent from students enrolled in each course (n=57 consented students in the first-year course, with course enrollment typically 60-65 per semester; n=61 consented students in the sophomore course, with course enrollment typically 60-70). Eight students were concurrently enrolled in both courses). Of the 92 consented students who completed the demographics survey, 15% were from rural communities across the two classes. Our rural students present a diverse set of characteristics that differ from urban and suburban students (Table 1).

PEDAGOGICAL STRATEGY

Broadly, our pedagogical strategy is guided by constructionism,[21] a theoretical stance that argues for meaningful, relevant learning experiences that engage learners in constructing their understanding and making it public. We sought to provide students with opportunities to learn about communities' needs and to see such work as a possible career path. We designed a pedagogical strategy to meet this need: community-inspired design challenges. Specifically, we define these as including the following attributes, which create a sense of realism (Figure 1).

- *Current: The design challenge addresses current issues actually faced by individuals or communities*
- *Contextual: The design challenge includes specific information tied to the individuals or communities*
- *Open: There are multiple satisficing answers*
- *Relevant: The design challenge is relevant to lives of the learners or to the lives of people they know*
- *Professional: The design challenge reflects the work of professional engineering*

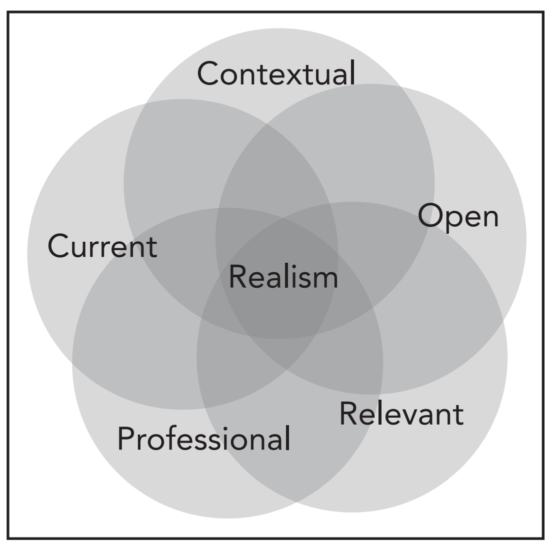

Figure 1. *Model of our pedagogical strategy.*

We developed several short design challenges for the first-year course but focus on two in this paper (Table 2).

In the antimicrobial challenge, students pitched their ideas for entrepreneurial applications of a new antimicrobial material. In the rural clean water challenge, students studied the 2015 Gold King Mine spill,[22] which affected communities in rural New Mexico. Students pitched their ideas for dealing with threats to clean water in rural communities, including water filtration methods and community-engagement strategies. In both cases, their pitches were to be no longer than 3 to 5 minutes, and students were instructed to concisely explain the problem and needs addressed by their design and share how their design would change customers' lives for the better.

We developed an algal biofuel design challenge for the sophomore-level course. Algae grows faster than land-based plants (*e.g.*, corn, sugarcane) and can be used as a source of fuel. Generating fuel from algae takes place in three production phases: growth, harvest, and extraction. Student teams were assigned to focus on one of the three production phases (growth, harvest, or extraction). Student teams focusing on the growth phase were asked to choose a community where critical growth requirements, such as carbon dioxide supply, type and density of culture, water supply, and exposure to light can be met. Separation of algae from its growth medium is carried out in the harvesting phase; student teams focusing on harvest researched techniques that would allow for a less energy-intensive process, including filtration and centrifugation. Extraction involves

TABLE 2
Attributes of our pedagogical strategy, as instantiated in our design challenges

Attribute	Antimicrobial challenge (First-year)	Rural clean water challenge (First-year)	Algal biofuel challenge (Sophomore)
Current	Based on recent research results by our faculty	Based on recent event and current threats to rural communities	Based on recent research and development efforts, including local efforts to create biofuel
Contextual	Students could choose a specific application	Rural communities, including the Navajo Nation, were affected; more could be affected in future	Students chose a community of less than 10,000
Open	Students proposed diverse applications (*e.g.*, cell phone covers, toys, makeup)	Students investigated water filtration/purification strategies and approaches to working with communities	Students investigated approaches to growing, harvesting, and extracting fuel from algae
Relevant	Students have experienced infections, are aware of antibiotic resistance	Students are aware of the threats to water in the Southwest United States	Many students are interested in the environmental or innovation potential of algal biofuel applications
Professional	Students did market research, identified needs, and proposed solutions to an entrepreneurial problem	Students did market research, identified needs, and proposed solutions to complex socio-technical problems	This is an active area of research and development. Students researched, understood needs, proposed designs

TABLE 3
Coding scheme for the first-year course pitches. We assigned a code of 0 if the student did not include the information and a code of 1 if they did include the information in their description, except for economic judgment, as noted.

Code	Student describes:
Personal story	A personal story gained from everyday experience
Conventional wisdom	Conventional wisdom or commonplace experiences gained from everyday settings
Rural knowledge	Rural knowledge or experience
Ethics	Ethical considerations related to people and/or the environment
Economic judgment	Cost as low (score = 1); high (score = -1) or without this judgment (score = 0).

TABLE 4
Coding scheme for the sophomore course assignment. We assigned a code of 0 if the student did not include the information and a code of 1 if they did include the information in their description.

Code	Student describes:
Rural knowledge	Rural knowledge or experience
Sourced knowledge	The source of their knowledge, providing a citation or stating a team member as the source
Ethics	Ethical considerations related to the environment
Innovation	An innovative technique for carbon dioxide capture directly from the atmosphere
Economics	Cost as a factor

removing the oil from the algae; student teams focusing on extraction contrasted two major methods—mechanical and chemical—based on handling and chemical safety. All three foci prompted students to link knowledge gained from the challenge to the course content by way of deliverables, which were submitted with each of the six homework assignments.

Data collection

Following informed consent, students completed a survey that included questions about their background and demographics. From the survey, only demographic data was used for the current study. We collected all student work on the design challenges. As long as at least one student in the team provided consent, we were able to collect and analyze the teamwork. However, to protect the privacy of students who did not give consent, we were not able to connect students' demographic data from the survey to their work. In the case of the first-year course, student work included worksheets that guided their research and designing, their presentations, and video recordings of their pitches. In the case of the sophomore course, work included decision matrix worksheets and project proposals.

Data analysis

We followed commonly used procedures for qualitative data analysis, including enhancing the trustworthiness and credibility by working iteratively to develop and refine coding schemes to analyze student work[23] and discussing the nature of disagreements in coding. We coded the pitches made by teams in the first-year course (Table 3). We coded student work on an assignment from the sophomore class (Table 4) in which students were asked to use a decision matrix to choose a source for CO_2.

RESULTS

First-year course

The first research question contrasted two design challenges to uncover any potential impact of rural perspectives. We coded the pitches teams gave at the end of two design challenges (antimicrobial product, clean water). In both cases, students provided market research and discussed the economic viability of their design solutions.

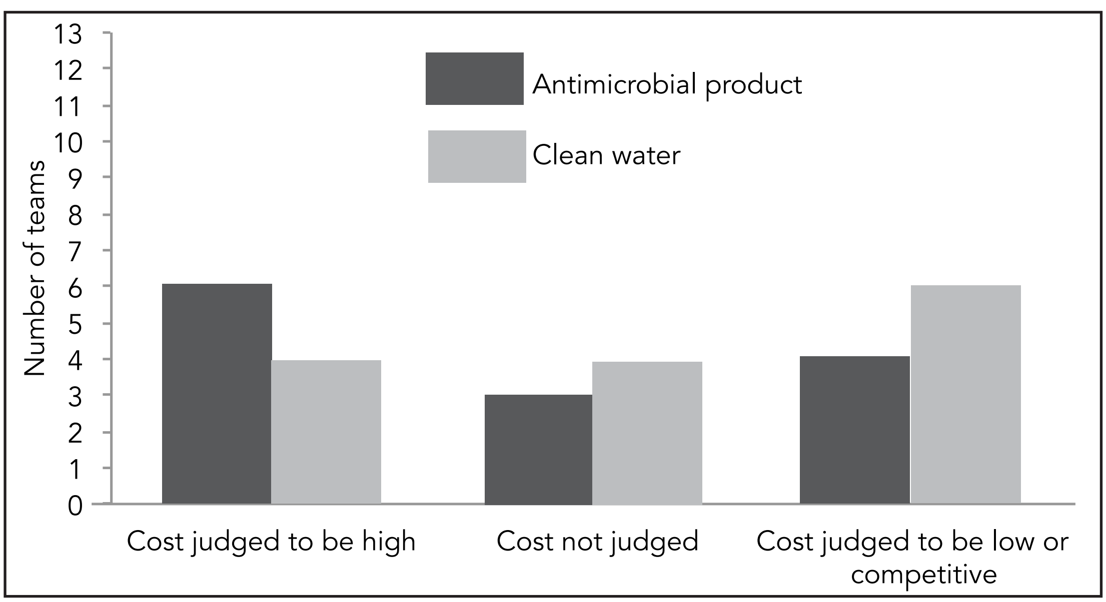

Figure 2. In the antimicrobial design challenge, six teams judged their cost to be high; four teams did so in the clean water challenge.

When teams admitted their cost was high, they commonly defended this cost from an ethics stance. In the antimicrobial product challenge, 83% (five teams) defended their high cost from an ethics stance and in the clean water challenge, 100% (four teams) did this (Figure 2). For instance, in the former, the team argued,

> *"We do realize that our product is quite expensive, but when it comes down to it, this has the potential to cut down—as he mentioned before, there have been many viruses, the Zika virus, the Ebola virus—that have been just spreading and it also causes—causes, uh, widespread panic and our—we feel like our product has the potential to cut that down and create safer environments and when it comes to human lives, we feel that the price, you can't really measure price against human lives. So, therefore, we feel that although it is expensive, in the long run, it will be worth it."*

Of the seven teams that shared rural knowledge in their pitch in the clean water challenge, six of those teams presented costs they judged to be low and articulated an economically viable plan for a rural community (Figure 3, next page). In contrast, of the six teams that did not share rural knowledge, five proposed plans that they judged to be high in cost. In each of these cases, they made ethics arguments to back their high cost, very similar to what we observed in the antimicrobial challenge. Three of the teams that shared rural knowledge and that presented a low-cost plan had presented high-cost plans—justified by ethics arguments—in the antimicrobial challenge.

Sophomore course

The second research question investigated how students in a core sophomore-level course leveraged rural knowledge as they designed an algal biofuel facility for a rural community.

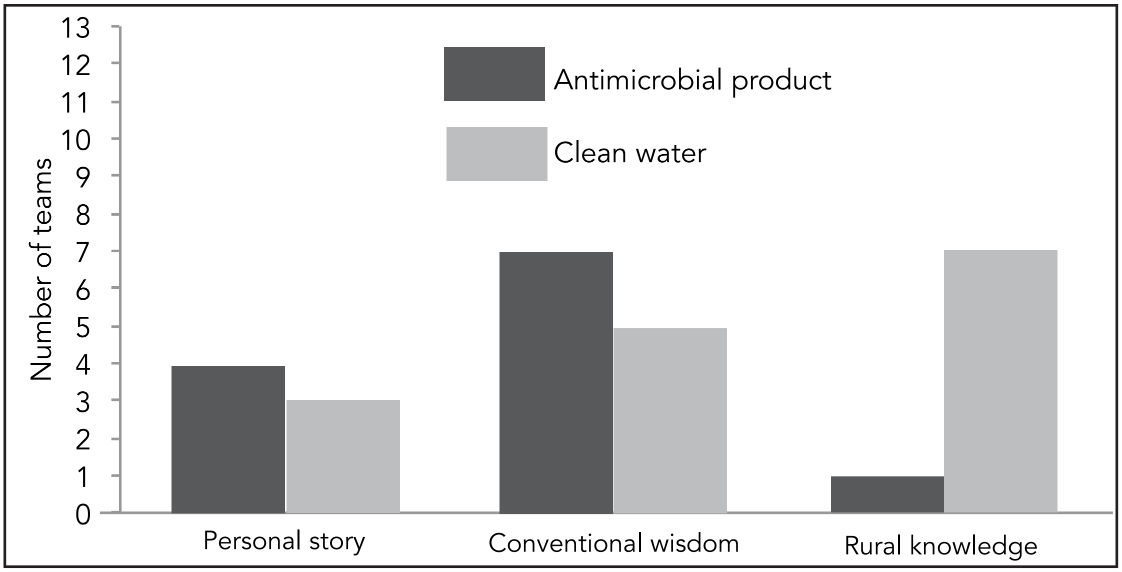

Figure 3. *Student teams' use of personal stories, conventional wisdom, and rural knowledge in the two design challenges.*

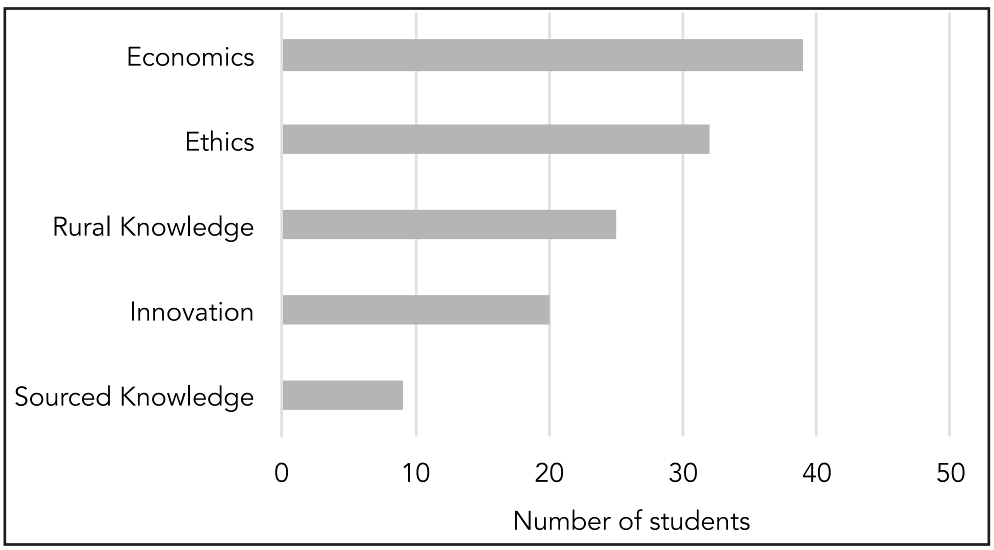

Figure 4. *Number of students using each type of criterion to evaluate carbon dioxide sources for algae production.*

We provided a decision matrix tool to support students to make decisions rationally. Students first worked individually to fill out the decision matrix, listing possible design options on the vertical axis and criteria to evaluate their choices on the horizontal axis. We asked them to first make their choice individually, prior to the class session. They then discussed and came to a consensus decision with their team, and then with other teams that had focused on the same production phase (growth, harvest, or extraction). These decisions came about through 10-minute roundtable consultations. Students used multiple types of knowledge to form evaluation criteria for selecting a carbon dioxide source (Figure 4). We found 76% considered economics, 63% mentioned environmental ethical issues the business can address, 49% shared rural knowledge, and 39% mentioned the potential for innovation. Only 18% cited a source for this information.

The community selected by the class was Vado, NM, and students who indicated they primarily grew up in rural communities were able to contribute their expertise about such communities, naming specific farms, power plants, and factories. Half of the students who indicated they primarily grew up in rural communities made reference to specific local carbon dioxide sources in New Mexico, such as Gonzales Dairy Farm, Inc., Valley View Dairy, Rio Grande Power Plant, and El Paso Electric Co. In contrast 49% of students from urban and suburban origins reported less-specific sources like "a Vado farm" and regional sources like "R-Cubed Energy Biogas plant located in El Paso, Texas." The remainder of students in each region (*i.e.*, rural or urban and suburban) identified broad carbon dioxide sources such as "capture from industrial waste" and "buy carbon dioxide."

We found 83% of students who grew up in rural communities attended to the economic aspects of their proposed sources compared to 70% of urban and suburban students. The rural and suburban students described costs associated with source preparation, operating, transportation, startup, and separation in evaluating the feasibility of the selected source of carbon dioxide. The other side of cost is the environmental impact of the selected sources. For example, one student noted "Bread Factories, we help Rainbow reduce carbon taxes and they help us afford CO_2." On further analysis, 88% of the students who reported growing up in lower income households commented on the cost of the process compared to 63% of the students who reported growing up in middle and high income households.

DISCUSSION AND IMPLICATIONS

Our community-inspired design challenges addressed current and relevant issues affecting individuals and communities in New Mexico. Understanding these design problems required consideration of specific contextual information, such as the specific resources available in Vado, NM, or myriad effects of the Gold King Mine spill in northern New Mexico. As students worked on these challenges, their work reflected that of professional engineers, and teams proposed different satisficing solutions. We found community-inspired design challenges to be a feasible alternative to service learning—which can be complex and challenging to manage[4]—but still supported students to apply content and empathize with human need. Similar to findings for project-based learning, our design challenges motivated students to commit significant time to learning.[12,17,18]

Our pedagogical strategy is guided by constructionism,[21] a theoretical stance that argues for meaningful, relevant learning experiences that engage learners in constructing and making their understanding public. The design challenges provided opportunities for our students to build on their prior experiences while addressing challenges that affect communities our students come from. Students had opportunities to construct their understanding as they framed the problem and developed possible solutions. Our students presented that understanding to an audience, which included members from outside the class such as industry partners, other faculty, and graduate students. In the future, we plan to additionally include clients and customers in the audience, as this can help students understand the importance of their decisions.

While we focused on rurality as an asset for supporting student learning, this approach could be extended to other settings. In our ongoing use of these design challenges, we have begun making students' assets explicit; for instance, in our most recent semester, we informed the first-year students of the results of this paper—that teams with rural expertise created more feasible designs. We then encouraged them to fill the gap in their knowledge if their team lacked a member from a rural community. This positioning of students as bringing expertise from their daily lives affirms students' belonging in the discipline. This approach is therefore not limited to rurality, but could also be used when addressing any specific community need. For instance, a design challenge focused on serving an inner-city, low-income community could instead position members of that community as experts.

LIMITATIONS

Our study was conducted in an unusual context—a research university that is Hispanic-serving. Our sample size was relatively small and did not involve any randomization or true controls. As such, our results may not generalize to other contexts. Limitations related to matching demographic data to teams also limit the degree we can be sure that rural students consistently contributed their expertise. For instance, some teams may have included rural students who simply did not contribute information from their own experiences. Future research should explore the group dynamics and instructional design characteristics that could encourage or hinder such participation.

CONCLUSIONS

We found that in both courses, students leveraged the rural experiences of their peers as they designed solutions to challenges that included rural concerns. Our approach extends prior work on CRT[7] and design projects,[10] showing that students can learn from each other as they work to understand rural concerns. Our work also demonstrates a more feasible approach to considering community need for high-enrollment courses where service learning may be challenging to implement. Asset-based classroom activities in chemical engineering that include rurality allow rural students to share expertise and make important contributions. By valuing their perspectives and sharing them, in tandem with developing design skills, we hope to instill in our students a strong commitment to considering ethical issues and context as they design.

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