Using Design Challenges to Develop Empathy in First-year Courses

Jordan Orion James, University of New Mexico

Jordan O. James is a Native American Ph.D. learning sciences student and lecturer at the University of New Mexico's School of Architecture and Planning in the Community & Regional Planning program. He has served as a graduate research assistant on an NSF-funded project, Revolutionizing Engineering Departments, and has been recognized as a Graduate Studies student spotlight recipient and teaching scholar. Jordan studies learning in authentic, real-world conditions utilizing Design Based Research methodologies to investigate design learning, in which he studies urban planners designing real-world community interventions and students who use design to learn. A member of the Grand Portage Band of the Lake Superior Chippewa Jordan obtained both his Masters of Community & Regional Planning and Bachelor of Media Arts from the University of New Mexico in Albuquerque where he lives with his wife and three daughters.

Dr. Vanessa Svihla, University of New Mexico

Dr. Vanessa Svihla is a learning scientist and assistant professor at the University of New Mexico in the Organization, Information & Learning Sciences program, and in the Chemical & Biological Engineering Department. She served as Co-PI on an NSF RET Grant and a USDA NIFA grant, and is currently co-PI on three NSF-funded projects in engineering and computer science education, including a Revolutionizing Engineering Departments project and a CAREER project, FRAME. She was selected as a National Academy of Education / Spencer Postdoctoral Fellow. Dr. Svihla studies learning in authentic, real world conditions; this includes a two-strand research program focused on (1) authentic assessment, often aided by interactive technology, and (2) design learning, in which she studies engineers designing devices, scientists designing investigations, teachers designing learning experiences and students designing to learn.

Chen Qiu M.Sc., University of New Mexico

Chen Qiu, M.Sc. has a Master's degree in Biomedical Engineering, and is currently pursuing a M.A. degree in Learning Sciences. Her past interests and accomplishments include instructional design in STEM, medical devices design, and neuroscience & neuro-engineering research. Her current focus involves designing training and instructional materials for engineering students/professionals utilizing SAM model, storyboarding, and task analysis.

Mr. Christopher Riley

Using Design Challenges to Develop Empathy in First-Year Courses

Abstract

This Complete Research study investigates how first-year design projects can support diverse students to begin developing an understanding of professional ethics and empathy as central to the work of designers. Our purpose is to examine student learning connected to a design challenge in two first-year courses: one in the chemical & biological engineering department and one in community & regional planning program within the school of architecture and planning department; both courses were taught in the same research university in the southwestern US, which serves a very diverse population. We conducted two iterations in a design-based research process. Design-based research involves testing both theory of and designs for learning under real world conditions. Our learning theory is that diverse populations like ours benefit from early design experiences that connect to their experiences, support them to build on their existing strengths, and build their professional identities.

Students in both classes completed a design challenge focused on providing a rural community with access to safe water in the event of contamination from acid mine drainage. In chemical & biological engineering, water filtration was foregrounded, whereas in community & regional planning, community engagement was foregrounded, but in both classes, their solutions had to include both aspects. We collected student work on the challenge, including students' presentations of their solutions. We developed a coding scheme to compare student work on the design challenges across the two courses.

We anticipated differences across the two courses, as past work has shown that students in the chemical & biological engineering course often arrived at solutions not feasible for rural communities to afford. We found that the community & regional planning students brought a more emotional sense of stakeholders and tended to avoid offering solutions.

Overall, our learning design supported students to consider different perspectives that had bearing on the design problem they were tackling. This approach efficiently encouraged students to begin caring about the needs of diverse stakeholders in a design project. While we did not have an authentic client, the design challenge itself proved to be relatable to our students, most of whom were already aware of the recent regional events that inspired the design challenge.

Introduction

Commonly, first-year undergraduate curricula in design fields like engineering and community and regional planning involve fundamental science and humanities courses; rarely are students provided with real-world problem solving experiences. However, it is through such practice that theoretical knowledge can be learned and understood in a professional context. This is especially important for diverse students who do not have much prior exposure to their fields of study. As a result of traditional introductory curricula, such students are more likely to drop out of the program when they encounter decontextualized and difficult theoretical knowledge. Thus, it is essential to allow students in the early stages of their undergraduate careers to learn through

application in a setting that mimics the actual working environment of design fields, such as through design challenges.

Design challenges usually involve real world problems that students can relate to their daily lives. Students can approach such problems based on their prior knowledge, including their cultural understandings of economic, environmental, societal and ethical values. Design challenges can enhance students' understanding of professionalism and ethics as designers. According to the NSPE Code of Ethics for Engineers, "engineers shall at all times strive to serve the public interest," and "shall be guided in all their relations by the highest standards of honesty and integrity" [1]. Design challenges push students to pay attention to the public interests and different perspectives of community members, government officials, etc., as they work to understand and solve design problems. In addition, design challenges require both teamwork and individual participation. This allows students to practice working with peers, similar to working within a community of professionals. This can aid students in understanding the values and functions of their fields as well as the required knowledge they need.

Background

Past research has demonstrated the benefits of early design experiences. Such experiences can support student understanding of engineering design learning, intent to persist, and identity. However, some design challenges fail to produce such results. We argue that students, especially those with limited prior knowledge of engineering practices, benefit from design challenges that integrate ethics and content, and engage students in considering multiple perspectives on design problems.

First year design supports professional engineering identity formation

It is well-documented that first year design projects support retention [2]. Such projects can help them develop their interests, identities, and confidence related to engineering [3]. Research on student persistence suggests that traditional approaches to instruction can discourage students who are the most inclined toward design work [4].

Although design projects can be beneficial, not all projects are equally effective. Analysis of how students engage with inauthentic design tasks revealed that student expectations of education settings can render design challenges ineffective [5]; for instance, when first-year students were tasked with coming up with renewable energy designs, analysis of experiences highlighted that the students completed the design work in a perfunctory manner, did not seriously consider user needs, and valued more traditional coursework over design work [5]. We argue that providing students with more authentic design projects can better engage them in understanding that design is the heart of engineering. However, first-year students may not be prepared to tackle design projects that depend on complex content. To address this, we developed design projects that leverage students' engineering assets and everyday experiences.

Asset-based pedagogy supports diverse learners

Many have advocated for student-centered approaches that meet our students where they are. While potentially beneficial, such approaches may be divided into two stances: those that aim to

address or fill students' deficits, and those that aim to build upon students assets. Deficit-based approaches place blame on the student for not knowing or being poorly prepared, and tend to view these gaps as needing to be addressed before students can reasonably progress to more complex tasks. In contrast, considering students' *funds of knowledge* means becoming familiar with the community and cultural experiences of our students, and helping them connect those experiences to the content and practices in the discipline [6]. Mejia and colleagues have demonstrated the success of this approach in engineering, highlighting that students from lower-income communities are able to creatively problem solve and have empathy for stakeholder needs [7-11]. In our own work, we have shown some of the ways our first-generation college students, and students from rural, low-income communities are actually engineering-design ready; born out of necessity, they have had to make do with limited means and have experience solving problems creatively and under constraint [12-15]. For instance, we positioned students from such communities as having relevant expertise, and they aided their teammates in attending to the feasibility of design solutions [13]. In the current study, which builds on our prior work, we specifically consider the ways an asset-based design challenge supported students to engage as designers, considering and valuing multiple perspectives on a complex yet accessible community challenge.

Design involves considering problems from multiple perspectives, building empathy and ethics

Effective ethics education should be threaded through the program and connected to design [16], providing students with opportunities to learn to value multiple perspectives and consider the ethical implications of their work. Although considered a core component of professional design practice, ethics education remains somewhat elusive [17]. Empathy and perspective taking are key components of ethics [18].

Designers fill gaps in their knowledge using empathy [19, 20]. By working to understand multiple and marginalized stakeholder points of view, designers can arrive at solutions that are ethical and humane [21-23]. Without this approach, designed solutions may be technical successes, but viewed by the people who must use them as failures. For instance, the Hoover Dam Bypass is such a case. The designers did not account for the negative impact it would have on the local Native American communities [24]. To prevent such failures, designers need to use empathy through various stages of design [20] as a practice [25]. Students also benefit from considering unintended consequences, accountability, and who benefits and suffers as a result of their designs [26] and constructing their own ethics arguments [27].

Another approach to ethics in design is the notion of the *ethics of care* [28], which emphasize responsibility, relationships and context [29]. This framework aligns well to the kinds of ethics judgments that are central to design, because designers, in taking up different points of view, should do more than just observe that such views exist; designers must also *care* about these perspectives enough to hold onto them and fold them into their design decisions, suggesting a more active stance than empathy [30].

One approach to supporting designers to develop this capacity is through humanitarian design projects [29]. However, a challenge for designers working on such issues is that it can be easy for them to take a do-gooder stance of helping the "disadvantaged" or simply focusing on one group at the expense of another [31]. Instead, by engaging *with* stakeholders to understand

problems and envision possible solutions is needed. However, such approaches are notoriously difficult to manage, especially in introductory coursework. We investigate an alternative approach that builds on a case study of a regionally-relevant and recent disaster, the 2015 Gold King Mine spill, inviting student design teams to design prevention or emergency response water filtration and community engagement plans with specific rural New Mexico communities in mind.

Methods

This research, undertaken as design-based research, investigates how first-year students in two design-focused degree programs were able to consider various points of view in addressing a design challenge. Design-based research involves testing a "humble theory" about learning [32] by instantiating it in a design and testing it under real world conditions [33-35]. The term "humble" characterizes the contextual nature of such theories, which should account for learning under specific conditions and suggest changes needed to transfer—rather than generalize—to other settings.

Research purpose

Broadly, we aimed to test our "humble theory" that providing diverse, first-year undergraduate students with team design challenges that connected to their everyday experiences would allow them to build on their funds of knowledge while addressing a realistic humanitarian design challenges and learning professional ethics. As is common in DBR, we formulate our research question by asking "how might"; this affirms our stance that the same designed experience can have different outcomes for different individuals.

- How might a scaffolded design challenge, based on a real crisis, support first year community & regional planning (CRP) and chemical & biological engineering (CBE) students to consider and care about multiple stakeholder points of view?
- How do these two groups of students differ in their orientation to stakeholder perspectives?

Participants & setting

We asked students enrolled in two first-year courses to volunteer to participate in the study: a Community & Regional Planning (CRP) course (n=24 consented to participate) and a Chemical & Biological Engineering (CBE) course (n=49 consented to participate).

In both courses, the majority of students were first year college students who were interested in graduating from the CRP or CBE program. There were a few sophomore and junior students who had changed from a previous major. In addition, a few students enrolled in theses courses as an elective to support degree requirements from other programs in the university.

The 3-credit CRP course met three times per week for 50 minutes in a traditional classroom with rows of tables and chairs all facing the front of the room towards the projector and lecturing instructor.

The 1-credit CBE course met one time per week for 50 minutes in a learning studio with seven round tables, a central instructor podium, and whiteboards and screens lining the walls. Each table included 9 chairs and three laptop computers.

In both courses, we introduced the design challenge with a design brief (see appendix) and a video. Students took on authentic roles in their teams. In the CBE course, they were asked to take on the roles of project manager, environmental engineer, community coordinator, and water systems engineer. In the CRP course, they were asked to take on the roles of lead community & regional planning manager, natural resources & environmental planner, community development planner, physical planner, and Indigenous community planner.

Data collection & analysis

Students completed two worksheets to scaffold their design process, which included prompts to help guide their discussions (see appendix). We first asked them to begin to define the problem by researching the 2015 Gold King Mine spill, acid mine drainage, community engagement strategies, and water treatment technologies. They used this information to consider the points of view of community members, farmers, and government employees and to describe the primary needs. The role of instructors during the designed intervention was to walk among the students to assist in answering any clarifying questions that arose and engage the students in conversation regarding their responses.

Three coders analyzed student work. Following a common qualitative analysis approach, we developed a coding scheme grounded in participants' own words, then refined this to also include a focus on the notions of care and community engagement [36]. We iteratively refined the codes to capture the diversity of responses (Table 1).

Table 1. We coded each section (reflection as a community member, as a farmer, as a government employee) with the same basic set of codes, adapted where noted

Code	Description	-1	0	1
First person perspective	Use of first person voice suggests student took up the perspective directly	They / passive voice	You / one	I
Emotion	Expressing emotions, including trust, was prompted by the question (How would you feel); not including specific emotions indicates lesser connection with the point of view.	None	One	Multiple
Water use	Describes specific uses of water or ways their water usage would be negatively impacted	Not detailed other than "use water"	Simple or single type	Detailed / multiple types
Multiple perspectives	From each particular role, students who more strongly take up the role tend to consider the impact that role	Considered self only	Considered self and closest others	Considered complex system (people, plants,

	has on others.			animals)
Solution	Describes detailed, possible solution(s) to the problem	No solution or very vague solution	Simple solution	Detailed solution
Responsibility	Describes who is responsible for or should be involved in the solution, with reference to the With / For / To framework	To (Government needs to fix the problem)	For (The designers know best)	With (Farmer or community member involvement in solution)
Cost	Considers cost of solution	Not considered	Simple description	Detailed explanation

Results and Discussion

Our first research question investigated whether our designed experience would support students to take up varied points of view. We asked them to consider three primary stakeholders, and explain how they would feel and what they would need as a community member, farmer, and government employee, in the event that a rural community's water had been contaminated by acid mine drainage. We found that students did consider different aspects of the problem when they took on the different roles of community member, farmer, and government employee (Figure 1).

First person perspective. Overall, they tended to take a first person point of view most easily in the role of community member, perhaps because this is the role closest to their own lives. For instance, a CBE team in the community member role explained, "I would feel a bit violated. We count on clean water for everything that goes on in our lives…." In contrast, the same CBE team in the farmer role began from an external point of view before shifting to a first person point of view, "In this situation, the livestock is the farmer's livelihood. This puts food on the table for the farmer's family. This also provides food for the community. It is the farmer's job to keep his/her livestock safe. From the Farmer's point of view, I would feel panicked that everything that I have worked hard for, will be destroyed."

Emotion. We conjectured that teams would express emotions most strongly in the community role, and less strongly in the farmer and government employee role, in part because of the degree to which they took up different points of view. While we did find that this was true for a few teams, overall, they expressed more emotions in the farmer role, and few emotions in the government employee role. We see this as revealing a perception that government employees should not engage in emotional ways; however, from our literature review, we would argue that the government employee role should engage via the ethics of care [28]. We did see this represented sparsely in the data, "If I were to work for the state government and it was my job to help in the efforts I would want to help the families, communities, and environment as much as possible." In future versions, plan to introduce the idea of the ethics of care to the students as a means to support them to develop more complex views.

Figure 1. Frequencies of codes by role (community member, farmer, government employee). Because the group sizes are so different, we avoid using percentages, which could be misleading.

Teams from both courses appear somewhat overwhelmed at the prospect of taking on the role of a government employee. For instance, a CRP team explained, "Being responsible for clean up, I would feel overwhelmed and responsible for the safety and health of community members." Another CBE team explained, "When problems like these occur, as a government employee it becomes very stressful and pressuring because the public and community are expecting one to address the situation and to find a solution quickly. And as we all know such a tasks carries a heavy burden, it can become very difficult to address a problem efficiently and correctly when there is pressure to get it done quickly." In contrast, while several CBE teams expressed similar sentiment, it was with less detail and emotional intensity, "I would be overwhelmed with the situation."

Water use. We also draw attention to how the teams attended to water use as they shifted across different roles. In general, they explained specific uses of water from the point of view as a community member, and to a somewhat lesser degree, as a farmer. Very few teams discussed how water is used when taking the perspective of a government employee. Teams mentioned a variety of uses of water, from personal and household needs (e.g., drinking water, showering, cooking, cleaning), to cultural and lifestyle needs (e.g., specific rivers that serve spiritual roles in local Native American cultures, fishing and boating), to work and income needs (water for crops and livestock).

Multiple perspectives. We conjectured that in the roles of community member and farmer, teams would consider more perspectives than in the role of the government employee, and this was confirmed in our analysis. In the community role, teams tended to consider themselves and their families or others in their communities. In the role of farmers, teams tended to consider themselves and their livestock. In a few cases, teams displayed a more complex and interconnected set of perspectives. For example, a CBE team in the role of farmer explained, "… the livestock is the farmer's livelihood. This puts food on the table for the farmer's family. This also provides food for the community. … I have nurtured and protected this livestock for years and even generations of farmers before me." In this response, the team considers both immediate, direct and longer term, indirect consequences.

Solution. We did not specifically prompt students to consider solutions, but many teams provided either simple or detailed solutions. Simple solutions focused on relocating people, simple water treatment solutions, and finding new, untainted water sources. For instance, a CBE team in the role of farmer provided a simple solution, "I would need help from the government to transport my livestock to a safer environment to ensure that everything will be right again." Detailed solutions included multiple elements and took into account the human element. For instance, a XBE team in the role of community member explained, "if [new] water is found, the source would be untrustworthy. Acid mine drainage happens so fast and suddenly that the contamination could spread easily throughout any water source nearby. Moreover, I would feel the need to move out of that town to another town or city where it is far from the contaminated water source and has fresh water. … The acid drainage would need to be cleaned up through some device capable of cleansing the water completely from the oxidized sulfides, and heavy metal ions. In addition, the abandoned mine site would have to be restored." In this example, we see that the team considers the role of trust in their ideas about possible solutions.

Responsibility. Overall, most teams placed the burden of solving the problem on the government. They seldom discussed involving communities members in the solution. An example from one of the CRP teams, in the role of farmer, that did proposed a community-engaged strategy displays they valued the idea, but they provided little detail, "Organizations and planners must work together with members of the community in order to find a sustainable and culturally sensitive way of distributing clean water from a safe and well regulated source to the farmland." Given the complexity of working with the rural communities they were considering, we hoped to see more community engagement in their discussion of solutions. We do not know if this reflects their expectation of what is realistic, or if they do not think the community members have useful contributions to make. While we did see some progress on this aspect in their final solutions in the form of research-based community engagement strategies discussed, most of these remained vague and decontextualized. As such, they would be unlikely to be effective. As we refine our approach, we plan to focus on this area more deeply. We may provide them with case studies of effective community engagement to help them understand the potential impact. We also plan to ask them to contextualize their community engagement plans further by providing more specific details about the plan in action.

Cost. Overall, few teams mentioned the cost of solutions. When they did, it was typically from the perspective of a farmer or government employee. Only one team (from the CRP course) provided a detailed account of why the cost would be complex, "If I were to work for the state government and it was my job to help in the efforts I would want to help the families, communities, and environment as much as possible but I would have to keep in mind that what I say and what I do has a lasting impact on how much I get paid and how much I am liked in my job. Although I would feel the need to help, I would need to figure out a way to clean up the spill as cheaply as possible. This sort of thing comes out of people's tax money, the more expensive our cleanup is, the more money comes out of taxpayer's pockets. My ultimate goal would be is to have a happy medium." More commonly, cost was mentioned as an unelaborated factor, such as this comment by a CBE team, "After some bounds are set, we can then dive into engineering solutions, that is, after a budget is declared."

We also conjectured that there would be a relationship between taking multiple perspectives and the complexity of proposed solutions. We analyzed co-occurrences of these coded across the two courses and the three roles of community member, farmer, and government employee (Figure 2). We see that in the role of government employee, the teams tended to take single perspectives. Overall, there were very few co-occurrences of detailed solutions and complex perspectives. The most common co-occurrences were between single perspective and simple solution, and complex perspective and no solution. We found teams express these across all roles.
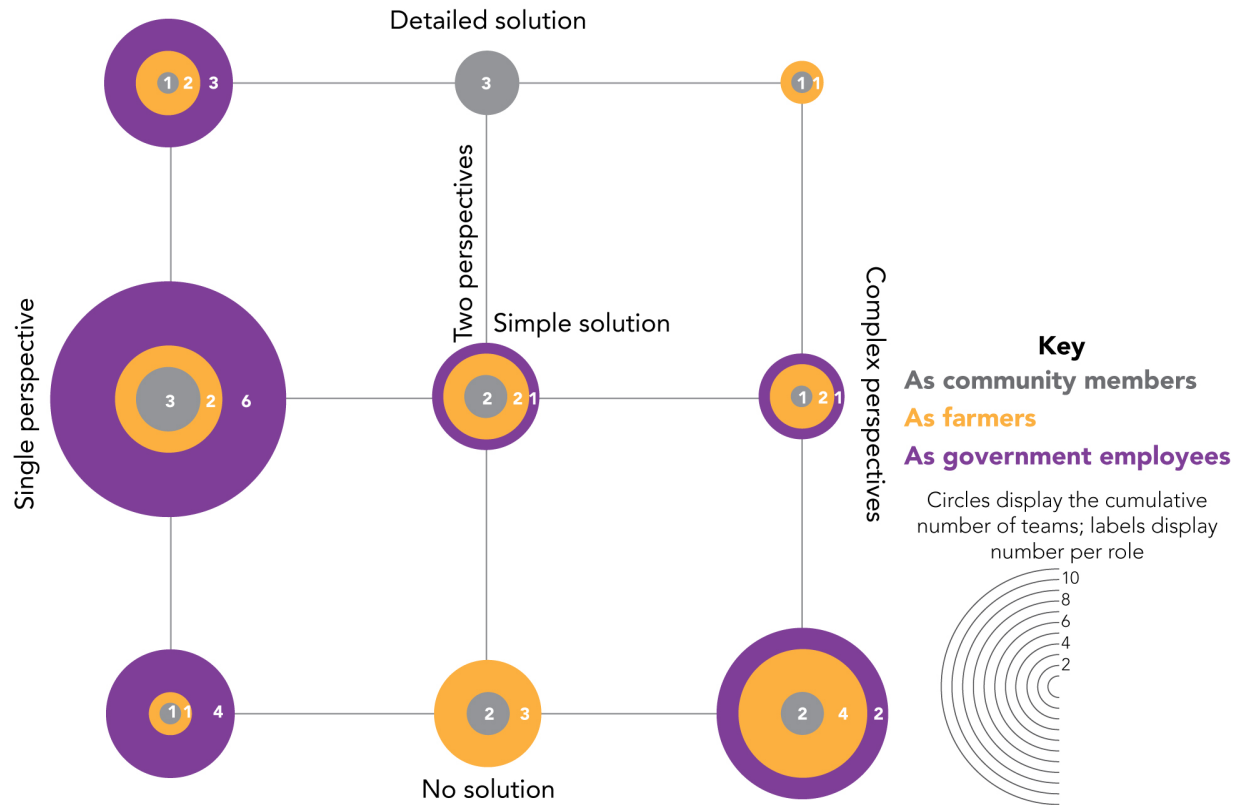
Figure 2. Map of co-occurrences of teams that proposed no, simple, and detailed solutions with teams that considered single, dual, or complex perspectives, while taking on the role of community member, farmer and government employee. Overall, and especially from the government employee role, students tended to express simple solutions with a single perspective. The next most common co-occurrence of codes was no solution and presenting the problem as complex. Given that this assignment was completed toward the end of problem framing, we hoped to see students in this space. We are therefore pleased that few students presented detailed solutions at this point.

Comparing CRP teams to CBE teams

When taking on the role of community members, CRP teams expressed more and stronger emotions than CBE teams. Only 38% of the CBE teams expressed more than one emotion, while all CRP teams expressed more than one emotion. For instance, one CRP team explained, "I would be <u>very angry</u> that an agency meant to keep my family and community safe and clean was responsible for such a <u>negative impact </u>on my most precious resource. I would be even <u>more upset</u> when I realized that they were doing nothing more than pretending the situation is under control when I can see in my failed cropland and in my neighbors' faces how much we are <u>in danger</u> of. I would be <u>sad</u> that the animals in the land around me are dying or gone altogether and that a location that was filled with sound and beauty is just yellow with hazy toxins. I think I would be <u>very worried </u>for the children and elderly of my community the most, but would realize that this situation affects EVERYONE in many aspects" (underlining added to draw attention to emotions).

In contrast, a CBE team explained, "I would feel <u>very sad</u> and <u>devastated.</u> I would now need to go out and buy water from the store, and would <u>not feel comfortable</u> using contaminated water in my house. I would need a safe water supply for my house." While three emotion words are used, the emotions seem expressed in a less intense way.

CBE and CRP teams differed in their tendency to propose solutions. When taking on the role of government employees, CBE teams provided more solutions than CRP teams. For instance, in the role of government employees, CBE teams mostly provided one solution, while CRP students mostly did not provide any solution. For instance, a CBE team explained, "I would need volunteers and connections with local figures and authorities to organize a community cleanup event." In contrast, CRP teams tended to consider the complexity of the problem without offering solutions, "Being responsible for clean up, I would feel overwhelmed and responsible for the safety and health of community members. If efforts are failed, media would blame me for the mess up and I will be held accountable." This difference may be in part due to differences in the instructional approach. During the first few class meetings, the CRP students were introduced to one of the fundamental issues surrounding their professional field— that there were no 'right' answers. Given the limited class time associated with the CBE course, this notion, fundamental to design process itself, was not emphasized explicitly.

Likewise, as government employees, CRP teams approached the problem with more perspectives than CBE teams. Half of the CRP teams provided more than one perspective while ten out of thirteen CBE teams only considered crops/animals. For example, a CRP team explained, as part of their response, that they needed to consider, "not only are people being affected but also our environment and the organisms within." Another CRP team explained, "Government employees seem to have a tough position. This can make their decision-making difficult and can lead to unhappy people." The CRP course was three credit hours, in contrast to the CBE course, which was only one credit hour. This additional time provided CRP students with more opportunities to practice the professional work of taking multiple perspectives on problems.

Conclusions

Overall, our learning design supported students to consider different perspectives that had bearing on the design problem they were tackling. This approach efficiently encouraged students to begin caring about the needs of diverse stakeholders in a design project. While we did not have an authentic client, the design challenge itself proved to be relatable to our students, most of whom were already aware of the recent regional events that inspired the design challenge.

We found few differences between the two courses, though it is important to note that our sample sizes were very small for the CRP course. The CRP teams' tendency to treat the problem as open rather than proposing solutions may be tied to the other instructional experiences they received about the nature of design (as ill-structured) as part of their course. While we hope to incorporate more of this into the CBE course in future iterations, the limited time available in a 1-credit course will pose a significant constraint, suggesting that this may need to be revisited in the later design challenges the students encounter throughout their core coursework.

Design-based research is a cyclic approach to refining both theory of and designs for learning. In this first cycle, we identified areas to improve or enhance. Future iterations will more directly

incorporate ethics of care as a lens as a mean to foster in our students an understanding of the role of professional ethics in their design work. We found that few teams provided contextualized community-engaged strategies, which suggests both areas for improvement in our design and affirms that this is a challenging concept for students to learn. This aligns to the suggestions of other researchers that these topics need to be threaded through the curriculum for students to develop complex professional ethics capacities, like the ethics of care.

Acknowledgments

References

[1]   National Society of Professional Engineers, "NSPE Code of Ethics for Engineers," Alexandria, VA2007.

[2]   D. W. Knight, L. E. Carlson, and J. Sullivan, "Improving engineering student retention through hands-on, team based, first-year design projects," in *Proceedings of the International Conference on Research in Engineering Education*, ed Honolulu, HI ASEE, 2007.

[3]   R. A. Atadero, K. E. Rambo-Hernandez, and M. M. Balgopal, "Using Social Cognitive Career Theory to Assess Student Outcomes of Group Design Projects in Statics," *Journal of Engineering Education,* vol. 104, pp. 55-73, 2015.

[4]   S. A. Atwood and J. E. Pretz, "Creativity as a Factor in Persistence and Academic Achievement of Engineering Undergraduates," *Journal of Engineering Education*, 2016.

[5]   A. Goncher and A. Johri, "Contextual Constraining of Student Design Practices," *Journal of Engineering Education*, vol. 104, pp. 252-278, 2015.

[6]   L. C. Moll, C. Amanti, D. Neff, and N. Gonzalez, "Funds of Knowledge for Teaching: Using a Qualitative Approach to Connect Homes and Classrooms," *Theory into Practice,* vol. 31, pp. 132-141, 1992.

[7]   J. A. Mejia, "A Sociocultural Analysis of Latino High School Students' Funds of Knowledge and Implications for Culturally Responsive Engineering Education," PhD, Engineering Education, Utah State University, Logan, UT, 2014.

[8]   J. A. Mejia, D. Drake, and A. Wilson-Lopez, "Changes in Latino/a Adolescents' Engineering Self-efficacy and Perceptions of Engineering After Addressing Authentic Engineering Design Challenges," in *Proceedings of American Society for Engineering Education Annual Conference*, ed Seattle, WA: ASEE, 2015, pp. 1-14.

[9]   J. A. Mejia and A. Wilson-Lopez, "STEM education through funds of knowledge: Creating bridges between formal and informal resources in the classroom," *The Agricultural Education Magazine,* vol. 87, pp. 14-16, 2015.

[10]   J. A. Mejia, A. Wilson-Lopez, C. E. Hailey, I. M. Hasbun, and D. L. Householder, "Funds of Knowledge in Hispanic Students' Communities and Households that Enhance Engineering Design Thinking," in *Proceedings of American Society for Engineering Education Annual Conference*, ed Indianapolis, IN: ASEE, 2014, pp. 1-20.

[11]   A. Wilson‑Lopez, J. A. Mejia, I. M. Hasbún, and G. S. Kasun, "Latina/o Adolescents' Funds of Knowledge Related to Engineering," *Journal of Engineering Education,* vol. 105, pp. 278-311, 2016.

[12]   V. Svihla, J. R. Gomez, S. Bowers, J. James, P. Prescott, and A. Datye, "Asset-based design projects in a freshman level course," in *Proceedings of the ASEE 124th Annual Conference and Exhibition*, 2017.

[13]   J. R. Gomez and V. Svihla, "Rurality as an asset for inclusive teaching in chemical engineering," *Chemical Engineering Education*, 2018.

[14]   J. R. Gomez, V. Svihla, and A. Datye, "Jigsaws & Parleys: Strategies for engaging sophomore level students as a learning community," presented at the Proceedings of the ASEE 124th Annual Conference and Exhibition, 2017.

[15]   J. R. Gomez, V. Svihla, A. Datye, V. Law, and S. Bowers, "Tapping into Diverse Student Assets to Enhance Design Framing Ability and Professional Identity Formation," in *American Institute of Chemical Engineers (AIChE) Annual Meeting*, San Francisco, CA, 2016.

[16]   National Academy of Engineering, *Infusing ethics into the development of engineers: Exemplary education activities and programs*. Washington, DC: The National Academies Press, 2016.

[17]   J. L. Hess and G. Fore, "A Systematic Literature Review of US Engineering Ethics Interventions," *Science and Engineering Ethics,* pp. 1-33, 2017.

[18]   J. L. Hess, J. Strobel, and A. O. Brightman, "The Development of Empathic Perspective-Taking in an Engineering Ethics Course," *Journal of Engineering Education,* vol. 106, pp. 534-563, 2017.

[19]   A. Coplan, "Will the real empathy please stand up? A case for a narrow conceptualization," *The Southern Journal of Philosophy,* vol. 49, pp. 40-65, 2011.

[20]   M. Kouprie and F. S. Visser, "A framework for empathy in design: stepping into and out of the user's life," *Journal of Engineering Design,* vol. 20, pp. 437-448, 2009.

[21]   T. Brown and J. Wyatt, "Design thinking for social innovation IDEO," *Development Outreach,* vol. 12, pp. 29-31, 2010.

[22]   J. Kolko, "Design thinking comes of age," *Harvard Business Review,* vol. 93, pp. 66-71, 2015.

[23]   W. B. Rouse, *Design for success: A human-centered approach to designing successful products and systems*: Wiley-Interscience, 1991.

[24]   K. Vortherms, "Engineering empathy," Arizona State University, Unpublished thesis, 2016.

[25]   J. Walther, S. E. Miller, and N. W. Sochacka, "A model of empathy in engineering as a core skill, practice orientation, and professional way of being," *Journal of Engineering Education,* vol. 106, pp. 123-148, 2017.

[26]   J. Schneider, J. Lucena, and J. A. Leydens, "Engineering to help," *IEEE Technology and Society Magazine,* vol. 28, 2009.

[27]   D. H. Jonassen and Y. H. Cho, "Fostering Argumentation While Solving Engineering Ethics Problems," *Journal of Engineering Education,* vol. 100, pp. 680-702, 2011.

[28]   M. Pantazidou and I. Nair, "Ethic of care: Guiding principles for engineering teaching & practice," *Journal of Engineering Education,* vol. 88, pp. 205-212, 1999.

[29]   R. C. Campbell, "How Can Engineering Students Learn to Care? How Can Engineering Faculty Teach to Care?," in *Engineering Education for Social Justice*, ed: Springer, 2013, pp. 111-131.

[30]   J. Strobel, J. Hess, R. Pan, and C. A. Wachter Morris, "Empathy and care within engineering: Qualitative perspectives from engineering faculty and practicing engineers," *Engineering Studies*, vol. 5, pp. 137-159, 2013.

[31]   M. L. De Souza, "Social movements as 'critical urban planning'agents," *City*, vol. 10, pp. 327-342, 2006.

[32]   P. Cobb, J. Confrey, A. A. diSessa, R. Lehrer, and L. Schauble, "Design Experiments in Educational Research," *Educational Researcher*, vol. 32, pp. 9-13, 2003.

[33]   The Design-Based Research Collective, "Design-based research: An emerging paradigm for educational inquiry," *Educational Researcher*, vol. 32, pp. 5–8, 2003.

[34]   V. Svihla, "Advances in Design-Based Research in the Learning Sciences," *Frontline Learning Research*, vol. 2, pp. 35-45, 2014.

[35]   A. L. Brown, "Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings," *The Journal of the Learning Sciences*, vol. 2, pp. 141-178, 1992.

[36]   J. Walther, N. W. Sochacka, L. C. Benson, A. E. Bumbaco, N. Kellam, A. L. Pawley, *et al.*, "Qualitative Research Quality: A Collaborative Inquiry Across Multiple Methodological Perspectives," *Journal of Engineering Education*, vol. 106, pp. 398-430, 2017.

Appendix A. Acid Mine Drainage Challenge: Design Brief

Introduction

Water is the most important resource to sustain life. Communities have relied on their local sources of water since the beginning of time. When these sources become threatened, communities can lose their sense of identity in addition to losing their way of life. Water sources in the American Southwest—already an arid environment with limited rainfall—face additional challenges.

In New Mexico alone, there are 15,000 abandoned mines and only a small percent have been remediated. Water flowing through abandoned mines or tailings from mining can mix with sulfide minerals to produce acid mine drainage, polluting the already limited water in the Southwest.

In August of 2015, over 3 million gallons of acid mine water from the Gold King Mine in Colorado were accidentally released into the Animas river by the Environmental Protection Agency during routine remediation activities. This river feeds into the San Juan River Basin which is one of the sole sources of water for many rural communities and the Navajo Nation [1]. The response to the incident left many who call the watershed their home feeling neglected and distrustful [2]. The Navajo Nation claimed the EPA misled the community about the extent to which the mine water was toxic [2]. They also claimed that the EPA did not accurately assess the cleanup procedures and whether or not they were successful. According to a report by the US Department of the Interior, the Gold King Mine spill was caused in part because of a lack of understanding of the "engineering complexity" of abandoned mines [1]. They warn that if teams don't include this expertise, we should expect more such disasters in the future.

As chemical engineers, you can help protect one of our most valuable resources: water. Your challenge is to design a comprehensive response plan, including community engagement strategies and choosing a treatment system that could filter water for an entire community in the event of pollution from abandoned mines.

Student Learning Outcomes

Students will be able to:

- research abandoned mines and acid mine drainage, as well as the Gold King mine spill as a case study, including the response by the EPA and the reactions of the Navajo Nation, and cite using the numbered citation style
- identify needs of community members
- analyze the feasibility of current treatment technologies
- estimate the costs and benefits associated with your plan
- propose a comprehensive response plan for Southwestern rural and Indigenous communities that are likely to be affected by acid mine drainage in the future
- pitch your plan

Appendix B: Acid Mine Drainage Design Challenge: Worksheet 1

Defining the problem

As engineers or community and regional planners, you can help protect one of our most valuable resources: water. Your challenge is to design a comprehensive response plan, including community engagement strategies and choosing a treatment system that could filter water for an entire community in the event of pollution from abandoned mines.

Your first task is to define the problem. This worksheet will guide you to do this by conducting research and considering the problem from different perspectives.

Gather information

In order to understand the problem, you will need to do some research. You should investigate:

- The Gold King mine spill as a case study, including the response by the EPA and the reactions of the Navajo Nation (at least 2 sources)
- Abandoned mines and acid water drainage (at least 2 sources)
- Current treatment technologies (at least 3 sources)
- Community engagement strategies that build trust (at least 1 source)

Source 1: Gold King Mine Spill

Make sure you can describe how the spill occurred, how communities were affected, how the EPA responded, and how the affected communities responded.

Citation:

Notes:

Source 2: Gold King Mine Spill

Make sure you can describe how the spill occurred, how communities were affected, how the EPA responded, and how the affected communities responded.

Citation:

Notes:

Source 3: Abandoned mines & acid mine drainage

Make sure you can explain how common abandoned mines are in the Southwest, how they can pollute our water, and the chemicals typically found in acid mine drainage.

Citation:

Notes:

Source 4: Abandoned mines & acid mine drainage

Make sure you can explain how common abandoned mines are in the Southwest, how they can pollute our water, and the chemicals typically found in acid mine drainage.

Citation:

Notes:

Source 5: Community engagement strategies

Your plan must include ideas for how to work with communities that may be mistrustful of outsiders and the government. Search for information on strategies for working with communities. You can choose to focus on rural or Indigenous communities. If you focus on the latter, consider the sovereignty of such communities.

Citation:

Notes:

Source 6: Water treatment

Investigate how others have ensured that communities have access to safe water. What kinds of filtration systems or chemical treatments are currently used? What are the pros and cons for this system? What can each system filter or remove from water? Consider including an image.

Citation:

Notes:

Figure/Image 1

Citation (follow guidelines here: http://www.15minutemondays.com/2014/03/10/give-photo-credit-credit-due/.

Paste figure here:

Source 7: Water treatment

Investigate how others have ensured that communities have access to safe water. What kinds of filtration systems or chemical treatments are currently used? What are the pros and cons for this system? What can each system filter or remove from water? Consider including an image.

Citation:

Notes:

Figure/Image 2

Citation (follow guidelines here: http://www.15minutemondays.com/2014/03/10/give-photo-credit-credit-due/.

Paste figure here:

Source 8: Water treatment

Investigate how others have ensured that communities have access to safe water. What kinds of filtration systems or chemical treatments are currently used? What are the pros and cons for this system? What can each system filter or remove from water? Consider including an image.

Citation:

Notes:

Figure/Image 3

Citation (follow guidelines here: http://www.15minutemondays.com/2014/03/10/give-photo-credit-credit-due/.

Paste figure here:

Multiple points of view

Designers use empathy to meet needs. This means they consider problems from points of view held by different stakeholders. Below, discuss and write your ideas for each point of view.

Community member. Imagine you live in a community whose water was unsafe due to acid mine drainage. Describe how you would feel, and what you would need.

Farmer. Imagine you are the owner of a farm and the water for your livestock appears unsafe, due to acid water drainage. Describe how you would feel, and what you would need.

Government employee. Imagine you work for the state government and it is your job to help in the cleanup efforts. Describe how you would feel, and what you would need.

Based on these points of view, what are the most important needs?

Appendix C: Clean Water Design Challenge: Design Solution

You can help protect one of our most valuable resources: water. Your challenge is to design a comprehensive response plan, including community engagement strategies and choosing a treatment system that could filter water for an entire community in the event of pollution from abandoned mines.

Take the research you have done and design a solution. This worksheet will guide you to generate ideas, and evaluate how well the your ideas meet the needs you identified. You will present your solution in a pitch.

Generate possible solutions

Identify at least 3 different approaches to treatment systems. For each, fill in the information in the table and include citations.

Treatment system #1 name (include citation):

Approximate cost	
Size of community it is scaled for	
Describe how the treatment system functions.	
What are some pros/benefits for this system?	
What are some cons/problems for this system?	
What kinds of contaminants can the system remove from water?	

Treatment system #2 name (include citation):

Approximate cost	
Size of community it is scaled for	
Describe how the treatment system functions.	
What are some pros/benefits for this system?	
What are some cons/problems for this system?	
What kinds of contaminants can the system remove from water?	

Treatment system #3 name (include citation):

Approximate cost	
Size of community it is scaled for	
Describe how the treatment system functions.	

What are some pros/benefits for this system?	
What are some cons/problems for this system?	
What kinds of contaminants can the system remove from water?	

Optimal solution

Designers look for optimal designs that meet needs in a balanced way while considering all requirements and constraints. For instance, a system that can filter everything out perfectly and is scaled to a small community, but that is prohibitively expensive is not an optimal solution. Based on your research above, which water treatment system is the optimal choice? Why?

Designing for social systems: Community engagement strategies

Technical designs often fail when we forget to consider the human element. The community members may be reluctant to accept outside advice. They may hold values and beliefs that have been threatened or marginalized. They may not be convinced that your water filtration system is needed. They might not trust government or industry representatives. Your complete design should include strategies for working with the community.