Learning from the experiences of Navajo engineers: Looking toward the development of a culturally responsive engineering curriculum

Shawn S. Jordan  |  Chrissy H. Foster  |  Ieshya K. Anderson  |  Courtney A. Betoney  |  Tyrine Jamella D. Pangan

The Polytechnic School, Ira A. Fulton Schools of Engineering, Arizona State University, Mesa, Arizona

Correspondence
Shawn S. Jordan, The Polytechnic School, Ira A. Fulton Schools of Engineering at Arizona State University, 7171 East Sonoran Arroyo Mall, Mesa, AZ, 85212.
Email: shawn.s.jordan@asu.edu

Funding information
National Science Foundation, Grant/Award Number: 1351728

Abstract

Background: Diverse perspectives, including those of Native Americans, are needed to drive innovation in science, technology, engineering, and math (STEM). Tribes such as the Navajo Nation are seeking to strengthen their communities, create economic opportunities, and improve the lives of their peoples by encouraging members of their tribe to become engineers. Research investigating how Navajo engineers experience and understand engineering design and practice in the context of their culture and community can provide insight into how to engage Navajo students in pathways to careers in STEM.

Purpose/Hypothesis: The purpose of the study was to identify and investigate the ways in which Navajo engineers experience, understand, and apply engineering design and practice in the context of their culture and community.

Design/Method: A phenomenographic approach was used to explore the ways that Navajo engineers experience and understand the phenomena of engineering design and practice in the context of their culture and community. A total of 20 Navajo engineers were interviewed for this study.

Results: Four qualitatively distinct lenses on how Navajo engineers experience and understand engineering design and practice embedded in the culture of the Navajo community were identified as (a) Navajo-centered behavior, (b) Navajo-centered purpose, (c) Navajo-centered strategy, and (d) Navajo-centered application.

Conclusions: The results of the study provide a deeper understanding of how Navajo engineers experience similarities and differences between Navajo culture and engineering design and practice, and provide a foundation for the development of culturally responsive engineering design curricula for classrooms in the Navajo Nation.

KEYWORDS
culture, design practice, engineering profession, Native American, phenomenography
1 | INTRODUCTION

This study explored the ways in which Navajo engineers experience and understand engineering design and practice in the context of their Navajo culture and community. Using the qualitative methodology of phenomenography, we investigated the research question: What are the ways in which Navajo engineers experience, understand, and apply engineering design and practice in the context of their culture and community? The goal of the study was to provide a deeper understanding of how Navajo engineers navigate the similarities and differences between Navajo culture and engineering design and practice, and to provide a foundation for the development of culturally responsive (Castagno & Brayboy, 2008; Ladson-Billings, 1995) engineering design curricula for K-12 classrooms in the Navajo Nation. The experiences and understandings of Navajo engineers provide valuable perspectives on lived realities that can inform the broader purpose of this work.

The mission of this study is grounded in the goals articulated by the Navajo Nation to enhance “the academic achievement of Navajo students in science, mathematics and technology” (Office of Diné School Improvement, 2019). Additionally, the tribal nations of Arizona, including the Navajo Nation, have called for tribal peoples to have “a future steeped in science, technology, engineering, and mathematics” to advance the status of their peoples and communities (Moore & Lane, 2014, p. 3). As the Navajo Tribe is the largest federally recognized tribe based on population of all the American Indian reservations in the United States (Norris, Vines, & Hoeffel, 2012) and the Navajo Nation is the largest American Indian reservation based on area in the United States (Indian Health Service, 2015), the Navajo tribal community has been a leader of change for tribal communities and their peoples in regards to science, technology, engineering, and mathematics education.

The engineering education community supports the goals articulated by the Navajo Nation. In 2006, the National Academy of Engineering reported, “The engineering profession needs the perspectives of American Indians...and reservations need the culturally relevant contributions of American Indian engineers” (p. 7). However, Native Americans remain highly underrepresented in the engineering workforce, representing 0.7% of the U.S. population in 2017 yet only 0.1% of all employed scientists and engineers (National Science Foundation, National Center for Science and Engineering Statistics, 2019). They remain highly underrepresented in the pathways from undergraduate engineering program to engineering practice. The National Science Foundation National Center for Science and Engineering Statistics (2019) reported that from 2006 to 2016 only 0.7% of all enrolled undergraduate students across all fields were Native American.

Efforts to support Native Americans, including Navajos, in the science, technology, engineering, and math (STEM) fields can be seen in programs and institutions such as Tribal Colleges and Universities (TCUs) within local Native American communities. The National Science Foundation initiated the Tribal Colleges and Universities Program in 2001 to support TCUs in improving STEM education programs (National Science Foundation, 2019). Although TCUs have increased the number of STEM-related degree programs available to Native American students in North America (American Indian Higher Education Consortium, 2011), only 7% of students enrolled in TCUs from 2009 to 2010 were pursuing STEM degrees (American Indian Higher Education Consortium, 2012). Continued efforts are needed, such as this study, to attract and support Native American students in STEM, and particularly engineering.

To support the participation of Native Americans in STEM, specific comprehensive approaches are needed to reform all segments of the educational pathway from preschool through graduate school (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011). For example, the K-12 system has failed to adequately prepare underrepresented students in STEM, resulting in a performance gap that can be attributed to disparities in resources (e.g., funding, qualified teachers, high-quality curricula, computer/Internet access) (May & Chubin, 2003). Also, the recruitment of minority students into engineering fields is hindered by the stereotypical images of scientists and engineers portrayed in the media (May & Chubin, 2003).

Strategies to broaden participation in STEM include providing precollege and undergraduate student enrichment and intervention programs (May & Chubin, 2003; Rodriguez, Kirshstein, & Hale, 2005), improving the effectiveness of teachers (May & Chubin, 2003; Rodriguez et al., 2005) and helping them build relationships among students, staff, and scientists (Lyon, Jafri, & St Louis, 2012), and engaging students in undergraduate research and graduate recruitment initiatives (Rodriguez et al., 2005). Additional strategies include introducing other systemic and infrastructure reform initiatives to increase the number of underrepresented students in STEM (May & Chubin, 2003; Rodriguez et al., 2005), improving the experiences of marginalized students on engineering design teams (Meadows et al., 2015), and developing new curricula (Rodriguez et al., 2005) that connect with different cultures. With support from both local communities and larger institutions, changes can be made to precollege and higher engineering education to remove barriers for Native American students (National Action Council on Minorities in Engineering, 2012). Specifically within higher education and professional practice, multiple entry and reentry points are needed in STEM (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011). According to the
President's Council of Advisors on Science and Technology (2012), to increase the number of college graduates with degrees in STEM, “all colleges and universities . . . need better connections among themselves and with other institutions to provide more entry points and pathways to STEM degrees” (p. 7). TCUs have been working to address this issue by increasing the number of STEM-related degree programs available to Native American students (American Indian Higher Education Consortium, 2011).

This study seeks to support broadening participation of Navajo students in STEM. A key contribution of this work is to provide a foundation of knowledge of how Navajo engineers experience similarities and differences between Navajo culture and engineering design and practice. The results from this study are being used in the development of culturally responsive engineering design curricula for K-12 classrooms in the Navajo Nation, answering calls for diversifying engineering by supporting Navajo students in their pathways in engineering.

Supporting the goals of the Navajo tribal community and the engineering education community, the overarching study came to fruition based upon a collaborative partnership between the researchers at Arizona State University and the Office of Diné School Improvement in the Navajo Nation Department of Diné Education. The study was developed as a result of a five-year partnership between the researchers and Navajo Nation community members, school administrators, and teachers, with the relationships based on mutual respect and trust. Prior to conducting the study, approval was obtained from the Institutional Review Board and a cultural review conducted by the Office of American Indian Initiatives at Arizona State University. All participants in this study were Navajo engineers who did not live in the Navajo Nation at the time of the interviews.

2 | AUTHORS' POSITIONALITY

This study explores Navajo cultural contexts and culturally responsive approaches for engineering education. As such, the work of Indigenous scholars has informed the perspectives and approach taken in this study (Kovach, 2005). The researchers conducting this study were guided by calls for researchers and educators to be transparent in their positionalities, personal histories, and perspectives in order to conduct reflexive and collaborative culturally responsive research with Native communities that will benefit them (Canada & Royal Commission on Aboriginal Peoples, 1996; Castagno & Brayboy, 2008; Haynes Writer, 2008; Kovach, 2005; University of Victoria Faculty of Human and Social Development, 2003). Within culturally responsive research, Indigenous and non-Indigenous scholars alike have the responsibility to uphold the integrity of culturally responsive work and acknowledge the cultural differences that influence and inform research (Kovach, 2005). This is particularly relevant to the engineering education research community, as the field of engineering is largely comprised of non-Indigenous peoples (National Action Council on Minorities in Engineering, 2012). Haynes Writer (2008) wrote of the importance of Indigenous perspectives to those outside the Indigenous community who work as “allies” in contributing to culturally responsive work: “Our stories and words are, as well, offerings to non-Indigenous people so they may come to know and move into ally-ship with us for that needed transformative work” (p. 10). This research is grounded in Indigenous perspectives, specifically Navajo perspectives, and the researchers are mindful of their role and influence in the research process.

Dr. Shawn S. Jordan and Dr. Chrissy H. Foster are Caucasian and of European descent, born in Indiana and Maryland, respectively. Ieshya K. Anderson is Tohono O’odham, born for the Tl’ááshchíʼí (Red Bottom Clan) of the Diné (Navajo). Her mother’s father is Naakétlį́į́h (Flat Foot People), and her father’s father is Tóódiłhí’ilí’ní (Bitter Water Clan). Anderson grew up on a small family farm in the Navajo Nation in the Four Corners area of New Mexico. Courtney Betoney is of the following clans: Kinyaa’aanii (Towering House Clan), Tóódiłhí’ilí’ní (Bitter Water Clan), Táchíí’níí (Red Running into the Water Clan), and Tl’íiítś lání (Many Goats Clan). Betoney grew up in the Navajo Nation in Ganado, Arizona. Tyrine Pangan is a first-generation Filipino immigrant born in Manila, Philippines, who immigrated with her family to the United States. The non-Indigenous research members have taken on the roles and responsibilities of serving as allies to Indigenous peoples and their communities. Together, the research team seeks to serve the Navajo people and their goals in partnership.

Jordan came to this research through his volunteer work as a judge for the Navajo Nation Science Fair. He became interested in the Navajo ways of doing engineering design and practice and began to collaborate with Department of Diné Education administrators to study Navajo cultural contexts in engineering design education. His motivation for research is grounded in a desire to transform engineering education in ways that sustain and further local communities. Foster came to Indigenous research also through her participation as a volunteer judge for the Navajo Nation Science Fair as well as through her participation in and service to the Phoenix American Indian Science and Engineering Society. She is motivated by the power of Indigenous stories in sustaining the local knowledge and cultural values of local communities, as exemplified by her dissertation research (Foster, 2016; Foster & Jordan, 2014). For Anderson, the research provided an opportunity for her to return to her Navajo community and contribute her engineering knowledge. She hopes to inspire Native youth to pursue careers in STEM. While pursuing her BS in Mechanical Engineering Systems from The Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona
State University, Betoney was driven to conduct the research because she saw many engineering parallels with the needs of her Navajo community, and she sought to guide and innovate how young Navajo people view this opportunity, no matter the difficulties they face in their lives. Pangan's motivation to participate in the research was driven by a desire to see a more diverse engineering field, one that is inclusive of many cultural backgrounds. As a research team, our intent has been to work together and with Navajo collaborators to achieve the goals of this project.

3 | RESEARCH FRAMEWORK

As this study explores how Navajo engineers experience and understand engineering design and practice in the context of their Navajo culture and community, it is grounded in a social constructivist perspective within the interpretive paradigm (Marton & Neuman, 1989; Prawat & Floden, 1994; Vygotsky, 1978). Using this theoretical perspective allows the experiences and understandings created through interactions between individuals and their environment to be revealed. This study is particularly concerned with the ways in which Navajo engineers interpret the cultural points of intersection between their local community culture (Navajo) and the cultures of engineering design and practice.

3.1 | Culturally responsive perspectives

The study is founded on the tenets of culturally responsive perspectives, which have traditions in literature on multicultural education and cultural difference (Castagno & Brayboy, 2008). Within educational contexts, culturally responsive perspectives “challenge traditional education research paradigms and honor multiple ways of knowing and engagement” (Berryman et al., 2013, p. 4). Culturally responsive perspectives reject deficit-based thinking about individuals from diverse cultural backgrounds (Howard, 2003) and promote an asset-based lens to better support diverse students in the classroom. For example, critical race theory of education (Ladson-Billings, 1995; Ladson-Billings & Tate, 2006) has been instrumental in drawing attention to the realities of racial inequities in education and how education may be transformed to support diverse students. This theory of education has been extended to Indigenous contexts by Native scholars Brayboy (2005) and Grande (2004) through their contributions of Tribal Critical Race Theory and Red Pedagogy, respectively. Other critical pillars of Indigenous scholarship in education include the contributions of meanings of place in the construction of traditional Indigenous knowledge (Cajete, 1994; Deloria & Wildcat, 2001; Semken & Freeman, 2008; Sutherland & Swayze, 2012). For the purpose of this study, contributions of Indigenous scholars in education are acknowledged as a critical base of scholarship that has made this work possible. The border-crossing framework, developed by Aikenhead (1996) for science education, was a core framework used in this study to illuminate crossing the borders between a Western-based engineering discipline and traditional Navajo culture.

3.2 | Border-crossing and cultural points of intersection

The study uses a border-crossing framework (Aikenhead, 1996) to examine the cultural points of intersection experienced by Navajo engineers. Border-crossing (Aikenhead, 1996) is grounded in a cultural perspective focused on how individuals interpret and reconcile disparate cultures and how this perspective influences their worldviews and experiences. This framework is based on the concept that culture is the combination of norms, values, beliefs, expectations, and actions of a group (Phelan, Davidson, & Cao, 1991), whereby individuals live culturally and make sense of the world through the lens of their culture (Gutiérrez & Rogoff, 2003; Moll & González, 2004; Nasir & Cobb, 2006). Within Aikenhead’s (1996) border-crossing framework, there is a “need to recognize the inherent border-crossings between . . . life-world subcultures and the subculture of science” (p. 2), or for this research the subculture of engineering.

Border-crossing has been primarily applied in science education to explore the ways in which nonmainstream students, such as Native American students, learn science content and what happens to their local cultural viewpoints and worldviews when they do so (Aikenhead, 1996). Relevant to this study, border-crossing provides a framework of processes for crossing between the cultures of the local Navajo community and engineering design and practice. Within the framework, the processes for crossing borders and boundaries of cultures include (a) enculturation, which refers to an agreement between an individual's interpretation of local and mainstream cultures and (b) assimilation, which refers to a disagreement between an individual's interpretation of local and mainstream cultures (Aikenhead, 2001; Aikenhead & Jegede, 1999). The many interpretations and possible outcomes resulting from these processes will be grounded in the dynamic, reflexive relationship between individuals and their environments.
Globalization creates complexity around the interpretations of cultural borders by “link[ing] communities of different cultural backgrounds” (Grimberg & Gummer, 2013, p. 12). Furthermore, “learners constantly cross-cultural borders among the many cultures to which they belong. Yet, there are points of intersection blurring these borders” (Grimberg & Gummer, 2013, p. 16). In STEM fields, this is particularly relevant as we aim to transform the production and distribution of goods and services and change fundamental social and economic patterns (Bugliarello, 2005).

In engineering education literature, there is a gap in the scholarship on the cultural border-crossings of practicing engineers from Native cultures. Researchers such as Clark, Dodd, and Cole (2008) have extended Aikenhead’s (1996) contribution of border-crossing to explore the learning experiences of students. Although their research did not focus on Native populations nor crossing borders between traditional and mainstream cultures, they applied the border-crossing framework to explore how learners come to be enculturated in learning settings by adopting the values of the learning community. Slay (2002) also drew from the work of Aikenhead (1996) to acknowledge learning environments as complex sociotechnical systems and propose considerations for multicultural learning settings. These examples provide an extension of the applications of border-crossing; however, there is a gap in the literature representing the ways in which Native American students cross cultural borders and specifically in the context of engineering learning. This study addresses this gap in the engineering education literature by exploring the sociocultural influences that affect the experiences of Navajo engineers as they are situated in a cross section of cultures between their local Navajo community culture and engineering design and practice.

A key aim of border-crossing framework is to make the cultural borders explicit so that teachers in the classroom may serve as cultural brokers in order to “sustain the validity of students’ own culturally constructed ways of knowing” (Aikenhead, 1997, p. 217). This role is supported by the efforts of culturally relevant pedagogy (Ladson-Billings, 1995), which calls for “an ability to develop students academically, a willingness to nurture and support cultural competence, and the development of a sociopolitical or critical consciousness” (p. 483). In the context of tribal cultures, Native scholars have called for Native American student’s cultural identity to be supported in the learning process (Castagno & Brayboy, 2008). As this research is situated within a larger design-based study focused on the development of culturally responsive models for Navajo students in middle schools in the Navajo Nation, both the border-crossing framework and the overarching aim of culturally relevant pedagogical goals frame this study.

Additionally, the National Academy of Engineering (2006) has contributed a list of “common ways of learning, teaching styles, orientations, and preferences” (p. 27) among Native American tribes in the United States, including:

- a global, or holistic style of organizing information (Backes, 1993; Davidson, 1992)
- a visual style of mental representations of information (Morton, Allen, & Williams, 1994; Rougas, 2000)
- a preference for a reflective style in processing information (Nuby & Oxford, 1996)
- a preference for collaborative approaches to tasks (Chavers, 2000)
- and a preference for dialogue between teachers and learners in which prior knowledge and experiences are interwoven with new material to raise understanding to a higher level (Chavers, 2000)

Native scholars have called for considerations of Indigenous ways of knowing and doing, and grounding new developments in education in the voices of Native Americans (Aguilera-Black Bear & Tippeconnic, 2015). This study is grounded in the perspectives and experiences of Navajo engineers to explore the ways in which they experience cultural points of intersection across engineering design and practice and Navajo culture, which will be used to inform culturally responsive curricula for Navajo middle school students in the Navajo Nation.

4 | DESIGN/METHOD

This study explores how Navajo engineers experience, understand, and apply engineering design and practice in the context of their culture and community. Since the design of the study relied on the voices of Navajo engineers engaging in engineering design and practice in the context of their culture, the methodology of phenomenography (Marton, 1981; Marton & Booth, 1997) was selected for this research.

Phenomenography is used “for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and phenomena in, the world around them” (Marton, 1986, p. 31). Individuals experience the same phenomena in qualitatively different ways, so phenomenography seeks to describe a “collective human experience of phenomena holistically” (Äkerlind, 2005, p. 72) from a constructivist epistemological perspective (Piaget, 1996) and social constructivist theoretical perspective (Prawat & Floden, 1994; Vygotsky, 1978). A phenomenographic analysis results in the key
components that comprise the variation under investigation (Bowden, 2000; Marton, 1981; Marton & Booth, 1997). These categories of description “contain a variety of conceptions and thus indicate that there are differences in the ways a phenomenon is understood” (Walsh, 2000, p. 29) and may be depicted as a taxonomy or hierarchy of understanding. Categories of description do not represent the individual responses from participants, but instead collectively reflect the understandings among a group of participants. Combining the categories of description with the relationships among the categories creates the phenomenographic outcome space (Marton & Booth, 1997).

### 4.1 Participants

Participants were selected using a maximum variation sampling strategy (Patton, 2002) to maximize diversity in participant experiences for this study (Akerlind, 2005). This sampling strategy is appropriate for a phenomenographic study as representative sampling may limit the exploration of the different ways people experience engineering design and practice in the context of Navajo culture. Additionally, the range of variation in the sample is expected to reflect the range of variation in the overall population (Marton & Booth, 1997). The sampling criteria used were participants' engineering discipline, years of engineering experience, whether they were raised on or off the Navajo Nation, whether they work on or off the Navajo Nation, and gender. The engineering sampling criteria were chosen to maximize perspectives across engineering disciplines. The Navajo cultural sampling criteria of being raised and/or working on or off the Navajo Nation were chosen to maximize the traditional versus nontraditional cultural paths of participants, which could impact the ways that they experience engineering design and practice. Gender was also chosen as a sampling criterion to illuminate potential differences in experiences between the matriarchal Navajo society (Locke, 2001; Witherspoon, 1975) and the male-dominated field of engineering (May & Chubin, 2003). Participants were recruited with the support of the American Indian Science and Engineering Society (AISES), the Navajo Nation's Department of Diné Education, and the Office of American Indian Initiatives at Arizona State University.

According to Bowden (2005), the number of participants should be large enough to see variation in experiences, but not so large that the data set becomes unwieldy. In this phenomenographic study, a total of 20 Navajo engineering practitioners participated, a number sufficient to reach saturation in variation (Trigwell, 2000). Furthermore, a sample size of 20 participants was appropriate for the population of Navajo engineers as Native Americans in engineering across all tribes represent “a mere fraction of other underrepresented minorities” (p. 1) with less than half a percent of the total engineering workforce (National Action Council on Minorities in Engineering, 2012). Supporting a small sample size as compared to the large sample sizes of quantitative studies, Pawley (2013) wrote that most studies “depend on statistical methods of generalization to understand the experiences of underrepresented people, despite the fact that the number of such people are usually too low to make analysis of them statistically significant” (p. 1). Additionally, the sample size in this study is comparable to similar phenomenographic studies published in the Journal of Engineering Education (e.g., 20 participants; Daly, Adams, and Bodner (2012) and 14 participants; Magana, Brophy, and Bodner (2012)). Table 1 summarizes the characteristics of the participants.

As shown in Table 1, participants differ in engineering profession, years of experience, whether they were raised and/or work on or off of the Navajo Nation, and gender. While participants can be categorized based on the sampling criteria, their experiences should not be generalized to the entire population of Navajo engineers. Rather, each participant's experiences represent one way of experiencing the intersection between engineering design and practice and Navajo culture.

### 4.2 Data collection

Semi-structured phenomenographic interviews were situated in discussions of participants' experiences to explore their understanding of the phenomena under study (Akerlind, 2005; Bowden & Marton, 1998; Marton & Booth, 1997). The interview protocol, based on prior work on defining design by Daly et al. (2012), was adapted to encourage participants to discuss engineering design and practice, Navajo culture, and the intersection of engineering design and practice and Navajo culture. Additionally, the theoretical stance of border-crossing (Aikenhead, 1996) informed development of the interview protocol to elicit discussion of intersections between cultures. The interview protocol was piloted and revised before data collection began. Table 2 provides an overview of the interview protocol; the full interview protocol is provided in Table A1 in the Appendix.

As shown in Table 2, the interview began with an opening statement, which positioned the constructivist stance of the work (see the table in the Appendix for the opening statement). The interview then used structured questions to learn of the participants' background and how participants define engineering and Navajo culture, followed by questions asking them to describe concrete experiences and how culture influences their design process. Based on the border-crossing framework,
interview questions focused on learning the boundaries and intersections between engineering design and practice and Navajo culture from the participant's perspective. Time permitting, additional experiences were discussed and compared with the initial ones, closing with questions about engineering and the Navajo community. Interviews typically lasted for approximately one hour, with the range being from 30 minutes to two hours. Interviews were audio recorded and transcribed for later analysis.

TABLE 1  Study participants in alphabetical order

| Pseudonym | Engineering criteria | Cultural criteria |
|-----------|----------------------|------------------|
|           | Engineering profession | Years of engineering experience | Raised on/off Navajo Nation | Work on/off Navajo Nation | Gender |
| Alden     | Mechanical and electrical | 25 | Off | Off | Male |
| Bonnie    | Renewable | 27 | On | Off | Female |
| Cadence   | Energy plant | 25 | On | Off | Male |
| Damon     | Supply chain management | 20 | On | Off | Male |
| Ernest    | Construction management | 9 | On | Off | Male |
| Fredrickson | Technology—Construction | 20 | On | Off and on | Male |
| Gerald    | Electrical | 16 | Off | Off | Male |
| Hannah    | Civil | 10 | On | Off | Female |
| Irene     | Technology | 14 | On | Off | Female |
| Jade      | Software | 19 | On | Off | Female |
| Kadin     | Software | 24 | On | Off | Male |
| Lanson    | Civil | 12 | On | Off | Male |
| Macy      | Mining and geological sciences | 6 | On and off | Off | Female |
| Nathan    | Mining | 30+ (retired) | On | Off | Male |
| Odin      | Petroleum | 3 | On | Off (on another reservation) | Male |
| Paul      | Technical illustrator (electromechanical designer) | 17 | Off | Off | Male |
| Quinn     | Renewable | 20 | On and off | Off | Female |
| Ryan      | Mechanical | 30 | On | Off | Male |
| Samantha  | Software | 7 | Off | Off | Female |
| Taylor    | Civil—Waste and water | 7 | On and off | On | Female |

TABLE 2  Overview of the phenomenographic interview protocol

| Section          | Example questions |
|------------------|-------------------|
| Opening statements | Structure and purpose of the interview |
|                  | Interview logistics |
| Background and definitions | How can engineering relate to your Navajo culture? |
|                  | How do you exercise values from your culture as an engineer? |
| Describing experiences | Can you tell me about an experience you have had doing an engineering project? |
|                  | How did culture influence the way that you worked on this project? |
| Comparing experiences | Can you describe another practical experience you have had that relates to engineering? |
| Community         | What role would you say that engineering has in your life as a Navajo? |
|                  | How could you help your Navajo community with engineering? |
| Closing           | Are there ideas or recommendations you might have for engineering education in Navajo Nation schools? |
4.3 Data analysis

The analysis of the phenomenographic interview data was highly iterative and based on prior phenomenographic studies in engineering education (Adams, Daly, Mann, & Dall’Alba, 2011; Daly et al., 2012; Light, Calkins, Luna, & Drane, 2009; McKenna, Yalvac, & Light et al., 2009; Micari, Light, Calkins, & Streitwieser, 2007). Importantly, data analysis was not conducted using predetermined codes derived from literature or theory; rather the data were analyzed inductively with the categories emerging from the data. Furthermore, the unit of analysis was a whole individual interview (Åkerlind, 2005) to reflect the holistic nature of the research question; therefore, the participants’ responses to individual questions were analyzed as a collective in accordance with the entirety of the interview.

The process summarized in Figure 1 was as follows: (1) multiple researchers read all of the transcripts and discussed the themes that emerged from the data (Lincoln & Guba, 1985); (2) participants were sorted into groups based on the emergent themes and “big ideas” observed in the empirical evidence (e.g., the participants' descriptions of the role of Navajo traditional teachings in engineering); (3) multiple researchers reread each group of transcripts to verify and challenge whether the participants belonged in a particular group; (4) detailed descriptions were written of how each group of participants experienced engineering design and practice in the context of Navajo community culture, relying heavily on direct quotations to provide rich, thick description (Geertz, 2003); (5) relationships between each group of interviews were identified and an emergent outcome space composed of categories of description (groups) and relationships among the categories was defined (J. Bowden, 2000; Marton & Booth, 1997) (e.g., those categories that included other categories but also contained their own distinct finding were identified); (6) multiple researchers reread the transcripts to double check and verify the outcome space categories of description (groups) and the relationships among the categories; (7) an outcome space (including categories of description and the relationships among them) was finalized and reported. The process was highly iterative and was repeated by the research team five times until the categories and descriptions fully captured the groupings. The data analysis and findings were a result of interpretive acts used by the research team to interpret the participants’ words to construct meaning and form the final outcome space.

One of the most challenging parts of the analysis process was clearly assigning each participant to a single group when their interviews included multiple strong themes. For example, participant Nathan fit strongly with participants Ernest and Kadin in their common discussion of how engineering can provide economic stability for Navajos. However, he also spoke extensively about how Navajo traditional teachings guide his behavior, making him fit strongly with participants Irene and Samantha. After extensive discussions among the research team and consideration of the whole-interview unit of analysis, we decided that Nathan fit most strongly with Ernest and Kadin and that the hierarchical nature of the outcome space would best represent Nathan’s discussion of Navajo traditional teachings.

FIGURE 1 Overview of phenomenographic analysis process
4.4 | Validity and reliability

This study upheld standards of validity and reliability, as guided by a quality research framework for interpretive engineering education research (Sochacka, Walther, & Pawley, 2018; Walther, Sochacka, & Kellam, 2013). Specifically, the study was designed to establish theoretical validation to guarantee the fit between the social reality under investigation and the theory generated through the use of maximum variation sampling strategy (Patton, 2002), a form of purposive sampling (Lincoln & Guba, 1985). By selecting participants to maximize variation in the study population, common patterns were identified that cut across the variations in the study population (Patton, 2002). A highly iterative process involving five researchers was used to independently analyze the data. To establish procedural validation, specifically that the features of the research design inherently improve the fit between the reality studied and the theory generated, a semi-structured phenomenographic interview protocol was designed to capture participant experiences of the phenomena under study. The highly iterative process for analysis also minimized the risk of misconstructing participants’ shared experiences of the phenomena.

Additionally, the study established the integrity of the interlocking processes of social construction with the relevant communities (communicative validation) by asking each participant to define the two key constructs under investigation: engineering design and practice and Navajo culture. These questions provided the research team with sufficient data to avoid abstractions in analysis not intended by the participants. In handling the data, consensus on the final results at each stage of analysis was reached among the five researchers who independently analyzed the data. Further, upholding standards of validity, the researchers constructed the interview protocol to explicitly explore the natural intersection between participants’ experiences of Navajo culture and engineering design and practice. Doing so ensured compatibility of the theoretical constructs with empirical reality. The findings are fully contextualized in participants’ individual experiences and, while not generalizable, are transferrable (Leydens, Moskal, & Pavelich, 2004) to an educational setting where the intent is to teach Navajo students about their culture and engineering design simultaneously. Ethical validation was considered from the time of conception of the study and continued throughout to establish integrity and responsibility throughout the research process.

While two of the authors are outsiders to the Navajo community, this study was conducted with the utmost respect for the Navajo people and culture, with the intent to encourage students to pursue higher education and careers in STEM fields. Bang and Medin’s (2010) work detailing methodological and ethical considerations for working with Native American communities was used to inform the design of this study (e.g., elder input and community participation in the research agenda). Navajo undergraduate research assistants who have lived in the Navajo Nation were also an integral part of the analysis process, and members of the Navajo community have been continually engaged in dissemination of the results to community members and at academic conferences. Process reliability was established by ensuring the research process mitigated random influences.

4.5 | Limitations

The primary limitations of this work are in the boundaries of the participant sample and methodology. For example, our participant sample consisted almost entirely of Navajo engineers who currently live and work outside of the Navajo Nation based on the available sample. We, therefore, do not make claims about Navajo engineers who live and work on the reservation. We also do not make claims as to whether our sample is representative of the larger population of Navajo engineers as there is a lack of detailed data to confirm this. We present the need for an expanded sample as an opportunity for future research. Also, while our methodology of phenomenography does not produce generalizable results, it does provide rich, in-depth description of experiences that are transferrable. Phenomenography could be applied again with a different unit of analysis, for example, by taking a subsection of the interviews. Additional study of the interviews might reveal interesting results, extending the description of experiences. This research presents one lens for analysis and discussion; applying additional lenses in the future has the potential to reveal additional results that could contribute to educational change. The final outcome space and the evidence that led to its development are presented in the following section.

5 | RESULTS

5.1 | Categories of description

Analysis of the data revealed four qualitatively distinct lenses of how Navajo engineers experience and understand engineering design and practice embedded in the culture of the Navajo community. The four categories of description are presented below along with excerpts from transcripts representing each category, acknowledging that each transcript was analyzed as a whole. Relationships among the categories of description are also described, in addition to the strongest themes in the categories. The
four categories of description are arranged in a hierarchical order in the phenomenographic outcome space shown in Figure 2. The diagram moves from the first category at the bottom to the fourth category, showing that Category 1 is the base category, Category 2 is a distinct lens of understanding also including Subcategory 1, Category 3 is another distinct lens including both Subcategories 1 and 2, and Category 4 is the final distinct lens that includes Subcategories 1 through 3. Table 3 lists the participants, ordered alphabetically within each category, associated with each category of description.

![FIGURE 2 Phenomenographic outcome space in hierarchical form]

### TABLE 3 Summary of participants associated with each category of description

| Pseudonym | Engineering profession | Category 1: Navajo-centered behavior | Category 2: Navajo-centered purpose | Category 3: Navajo-centered strategy | Category 4: Navajo-centered application |
|-----------|------------------------|-------------------------------------|------------------------------------|-------------------------------------|---------------------------------------|
| Irene     | Technology             | ✓                                   |                                    |                                     |                                       |
| Samantha  | Software               | ✓                                   |                                    |                                     |                                       |
| Alden     | Mechanical and electrical | ✓                                 | ✓                                  |                                     |                                       |
| Ernest    | Construction management | ✓                                  | ✓                                  |                                     |                                       |
| Jade      | Software               | ✓                                   | ✓                                  |                                     |                                       |
| Kadin     | Software               | ✓                                   | ✓                                  |                                     |                                       |
| Lanson    | Civil                  | ✓                                   | ✓                                  |                                     |                                       |
| Nathan    | Mining                 | ✓                                   | ✓                                  |                                     |                                       |
| Cadence   | Energy plant           | ✓                                   | ✓                                  | ✓                                   |                                       |
| Damon     | Supply chain management | ✓                                 | ✓                                  | ✓                                   |                                       |
| Fredrickson | Technology—Construction | ✓                                | ✓                                  | ✓                                   |                                       |
| Gerald    | Electrical             | ✓                                   | ✓                                  | ✓                                   |                                       |
| Hannah    | Civil                  | ✓                                   | ✓                                  | ✓                                   |                                       |
| Paul      | Technical illustrator (electromechanical designer) | ✓                          | ✓                                  | ✓                                   |                                       |
| Ryan      | Mechanical             | ✓                                   | ✓                                  | ✓                                   |                                       |
| Bonnie    | Renewable              | ✓                                   | ✓                                  | ✓                                   | ✓                                     |
| Macy      | Mining and geological sciences | ✓                         | ✓                                  | ✓                                   | ✓                                     |
| Odin      | Petroleum              | ✓                                   | ✓                                  | ✓                                   | ✓                                     |
| Quinn     | Renewable              | ✓                                   | ✓                                  | ✓                                   | ✓                                     |
| Taylor    | Civil—Waste and water | ✓                                   | ✓                                  | ✓                                   | ✓                                     |
5.1.1 | Category 1: Navajo-centered behavior

This category represents a distinct way of experiencing the intersection between engineering and Navajo culture as Navajo traditional teachings guide behaviors in all aspects of social life, including the engineering context. The Navajo traditional teachings passed down from Elders, families, and communities guide behavior in life and in engineering work and guide interactions and engagement with engineering teammates and managers. For example, Navajo traditional teachings emphasize the importance of listening, being respectful, and collaborating with others as can be seen in the two excerpts below:

> When you're growing up, you're taught more. Our values are more about how we treat people, how we carry ourselves, the respect, who we have respect for and always have respect for our Elders.

(Irene, Engineering Technology)

> I think the differences between myself and a lot of my coworkers is I...I listen. Because growing up, it's like, you have your aunties and they talk and talk and sometimes they lecture you and you just have to sit there and listen and take it, respect them. I have a lot of coworkers who are more western society. Where they always try to speak up and like be noticed, and don't necessarily listen. And so sometimes they jump the gun or they don't hear the whole story. They kind of waste time because they waste time doing something but if they would just listen, they would have gathered all the evidence before.

(Samantha, Software Engineering)

For Category 1, the foundation of all categories and represented within all participants' experiences, Navajo cultural knowledge embodies a value system to live by, including in their practice as engineers.

5.1.2 | Category 2: Navajo-centered purpose

This category, which is inclusive of the experiences within Category 1, also distinctly represents experiences of engineering having specific purpose within Navajo life. Two subcategories emerged from the data, embodying two distinct purposes: (a) engineering has the purpose and potential to improve life on the Navajo reservation and (b) engineering has the purpose and potential to provide economic stability for Navajos.

The first subcategory is related to the day-to-day life on the reservation and the need to improve the quality of life (e.g., water quality and irrigation systems for agriculture), basic infrastructure (e.g., housing), and practices (e.g., caring for land and cattle). Within this theme, Navajo culture and engineering are experienced as compatible because both require discipline, a strong work ethic, and working with problems with constraints as participants Lanson and Jade describe below:

> When I was growing up, my parents taught me you've got to help people. If somebody is doing poor, you help. Obviously, I get paid for it, I don't do it for free. I guess I do it for free sometimes. I do a lot of water projects. We bring water to where there's no water before. We drill wells, or we bring a pipeline into a small community. I think my Navajo thinking of helping somebody, we're bringing water into people's homes where a person is not capable of walking anymore. It's a more sanitary option for them. It's a lot easier for them to go to the restroom because they have plumbing. Also, vice versa is bringing the water out of the home. A lot of the bacteria associated with human waste is removed from the house. Also just bringing the clean, potable drinking water versus them hauling water from an unmonitored well into their home. Instead, we're bringing clean, potable water into the homes, obviously, reducing all kinds of diseases you could get from drinking bad water. I'd like to think that I'm helping these people or these communities out by bringing nice, clean water.

(Lanson, Civil Engineering)

> I would say that learning just those skills of creating a pathway, grading your road to get to the main highway. I lived out in a very rural area on a dirt road and had to figure out how to get out in the winter times and how to get out during the winter seasons. You had to try to figure out different roads or how to get out of mud or how to drive on icy roads and stuff like that. You could get stuck and get off the road and how to get yourself out. Just to be self-sufficient that way.

(Jade, Software Engineering)
The second subcategory, engineering has the potential to bring economic stability to Navajos, is experienced in terms of monetary stability. Engineering is viewed as a field with the ability to provide well-paying jobs, specifically jobs that provide opportunities for Navajos to provide for their families. This subcategory embodies the hardships that individuals who live and were raised on the Navajo reservation face and how an engineering job provides them opportunities including monetary stability:

"Engineering is a very big thing on the res. You'd be surprised. In high school you ask a group of students, half of them want to be engineers. It's weird because that's all you'll see. On the res, that's what they'll preach, engineers, doctors, nurses. That's how you're going to make it. [...] I make it a point where, "I'm Navajo. I grew up poor, in poverty. I've been through it so I'm happy to be here [with an engineering job]."

(Ernest, Construction Management Engineering)

For Category 2, engineering has purpose in Navajo life with real-world implications, including having the potential to improve the ways of life on the reservation and the prosperity of the Navajo people through economic stability.

5.1.3 | Category 3: Navajo-centered strategy

This category embodies the experiences within Categories 1 and 2 and also distinctly represents experiences of the ways in which Navajo culture informs the processes and strategies applied to solve engineering problems. Two subcategories emerged from the data representing distinct knowledge and processes that inform strategies for engineering: (a) Navajo traditional knowledge is used to solve engineering problems and (b) Navajo visualization strategies are used to understand engineering problems.

For the first subcategory, Navajo culture and its traditional teachings provide a foundation for life, specifically principles and knowledge for living. The foundation provided from this traditional knowledge guides the ways in which engineering problems are approached. For example, a holistic perspective, stemming from Navajo traditional teachings, drives problem solving and, with this approach, all things are considered when doing so, including dimensions that may not be part of the technical aspects of the engineering problem:

"I would say it has to do with. . . . The Navajo culture is very complex, but the Navajo culture relies on. . . . The basis of Navajo culture is our ceremonies. The way we use what's given to us naturally, through the earth, through the sun and everything that's handed down to us from our ancestors. Everything that was developed that we as Navajo people, from ceremonies, to our creation story, our myths of first man, first woman. They're not really myths we believe that. How the earth was formed, how Navajo people came into this world, the fourth world. That's who we are as Navajo people. As engineers, we use that. First thing I always look at as an engineer, I would look at the big picture. If you get a problem, sometimes we get involved in the minute details first, but as an engineer, we have to take a step back and look at the big picture as a whole and say "Okay, what is the actual problem?" If we solve this, we're not looking at just the symptom anymore; we're looking at the whole problem. You want to encapsulate not to just solve whatever the symptom is. Say a pump's not running right. If you fix this pump continuously every month for. . . At the plant, there's something else that's causing this pump to fail. Is it too small? Is it the wrong size? You got to look at the big picture of why this pump is failing.

(Cadence, Mechanical Engineering)

The second subcategory, Navajo visualization strategies are used to understand engineering problems, is related to the visual aspects of the Navajo culture and the ways in which visual approaches are used to understand life and guide thought processes, including engineering problems:

"I think Navajos are very visual in their understanding, so I had to actually get down there and crawl in this tiny crawlspace to actually see. If I read instructions, it doesn't really make sense, but if I go and actually see it. I love YouTube so much, I want to learn how to replace my alternator in my van, and they have the videos for that, I'm like, oh, yeah, I can do that, yeah, I can do it, no problem. But I read a manual, I can't. If it can make sense to me visually, then I can write it and I can, want to make sure that I put in the right pictures for somebody who might be like me. I think that's how Navajos are, they're very visual, in their thinking and also in their communicating.

(Damon, Civil Engineering)
5.1.4 | Category 4: Navajo-centered application

This category embodies the experiences in Categories 1, 2, and 3 and also distinctly represents experiences of applying engineering within a Navajo cultural framework. Two subcategories emerged in terms of the application of engineering within a Navajo cultural framework: (a) engineering has the potential to be applied to create solutions for future generations and (b) engineering can be applied for stewardship of the land.

For the first subcategory, the need to create engineering solutions that are sustainable and have positive, long-term impact is informed by Navajo culture and traditional teachings. In turn, sustainable solutions that are created for the benefit of community will have the potential to aid the Navajo reservation and the broader society as expressed by Bonnie, Quinn, and Taylor:

*That vision has to keep in mind that in the long run you're helping to save, hopefully in the broader sense, you're helping to save the planet.*

(Bonnie, Renewable Engineering)

*In Native groups you hear about looking out for 7 generations.*

(Quinn, Renewable Engineering)

*The needs are great, and so helping them is just being able to address those needs. Coming up with innovative solutions and long-term solutions to them, not just immediate. Not just something immediate that's only going to last for a little while.*

(Taylor, Civil Engineering)

The second subcategory embodies the responsibility to use the experience and knowledge as an engineer to minimize harm to the land and to conduct engineering design and practice in a responsible, culturally appropriate way. Engineering is seen as potentially contradicting Navajo culture through the harm that it can do to the land. This contradiction is reconciled by taking responsibility to balance the need to respect the Earth and the need to improve life through engineering work. This subcategory represents the experience of Navajo engineers working with tribal communities, including the Navajo community, as critical. The perspectives of Navajo engineers, as members of their communities, strengthen communication with the tribal communities and improve the intent and conduct of engineering work:

*Well, I mean eventually it did because I think a lot of like Navajo's culture is very much focused on making a positive difference and doing something good. . . . When I was working for the Tribe as an engineer, I really saw that. I mean, the permitting itself is not that fun and it's not. It gets a little routine. It's not that interesting like engineering wise, but it is definitely more, it was way more rewarding in the sense that I was working with Navajos. I was working for Navajos and I felt like I was contributing and I think that made a big impression on my family. A lot of people would just comment like everywhere that we went for meetings . . . When they heard I was an engineer most of the tribal of people would be like, “That is really good that you're doing that.” . . . When a lot of the resources were developed on the reservation, there were no qualified Navajo engineers to help out with like drafting legislation, figuring out the environment impact, figuring out the impact on the people.*

(Macy, Mining Engineering and Geophysics)

5.2 | Relationships between categories

Across the four categories of description, the outcome space represented lived experiences as told by 20 Navajo engineers. These Navajo engineers represented individuals who were successful in their endeavors to pursue higher education and careers in engineering. As the Navajo engineers from this study shared their experiences and as their experiences shared commonalities based on the four categories of description, they offered insights for interpreting the realities of the cultural
points of intersection between Navajo community culture and engineering design and practice. These insights included (a) tensions between the boundaries of Navajo community culture and engineering design and practice, (b) compatibilities between Navajo community culture and engineering design and practice, and (c) the values that Navajo community culture and engineering design and practice can bring to one another. These themes, which are explored in the following sections, were structured within a border-crossing framework, showing that the Navajo engineers participated and had experiences with local Navajo and engineering design and practice cultures. The Navajo engineers possessed a valuable knowledge base within both spaces and ways to navigate the sociocultural boundaries.

5.3 | Boundary tensions between the Navajo community culture and engineering

The Navajo engineers in this study represented a range of experiences, having grown up on or off the reservation, working within different engineering disciplines, and working on or off the reservation. Across their experiences, the participants had social expertise (Nicolini, Gherardi, & Yanow, 2003), or specific knowledge learned through interactions within specific social, cultural, and historical contexts of Navajo community culture. The social expertise of their local Navajo community culture provided insights into the tensions between the Navajo community culture and engineering design and practice, for example, the difficulties in transitioning from living on the reservation to off the reservation to pursue higher education and careers in engineering. This decision led some participants to feel detached from their culture and to seek ways to connect to their Navajo community culture by returning home. Additionally, some participants discussed the cultural differences between Navajo community culture and engineering workplace culture, including the Navajo values for respect, listening, honesty, hard work, and respect for women that were not interpreted as being part of engineering design and practice cultures. These insights were introduced in the participants’ experiences in Category 1 (Navajo-Centered Behavior) and were represented in the participants’ experiences in the second, third, and fourth categories. These insights also speak to the cultural differences between the Navajo community and the engineering design and practice community. For example, Kadin, a software development engineer, spoke about the difficulties he faced when he left home for college:

> Living in the dorm was easy because I’ve been doing it all my life. With the transition before, dormitory living was, there was Navajo boys everywhere, so there was always, it didn’t feel any different, but when I got to college, there was nobody. It was just me with a whole bunch of other people that I had never, that I do not know. For the first two weeks I think, I got really homesick. The saving thing about it was, I found out there were other Navajos. . . . AISES [the American Indian Science and Engineering Society] was around at that point, that’s how I got to know other Navajos.

Regarding the differences in workplace culture, Hannah, a civil engineer, explained:

> Just kind of going back to the values that my parents taught me. . . . I think it’s just working hard, and not expecting to get something for free. You work hard for everything that you have. . . . You know we have a kinship system. Within that kinship system, stems respect and the focus on relationships and relationship building. . . . You know, a lot of my co-workers are not Navajo. I still find a way to relate to them, to establish a relationship. You know my Mom, my parents, and even culturally, you’re taught to show respect, to value relationships. I think that stems from that. I sometimes see that in my co-workers. Not a whole lot in the workplace, just because sometimes it’s every man for himself, sadly.

Ernest, a construction management engineer, also explained:

> Being in the professional world is very tough because you’re taught to be tough. In my career, you’re taught to be dominant. . . . Me, I’m not. I was raised differently. . . . My family values respecting others. And that’s where I think it comes in to play, is respect. I’ve seen in the professional world, a lot of people don’t have respect for each other. All they see is money and time. But to me, it’s not that.

Another insight concerning the tensions between Navajo community culture and engineering design and practice included the limited engineering opportunities in the Navajo Nation, specifically limited STEM education and STEM role models for Navajo youth, limited jobs in the Navajo Nation for Navajo engineers, and limited technologies in the Navajo Nation. This
insight was introduced in the participants’ experiences in Category 2 (Navajo-Centered Purpose) and represented in the participants’ experiences in the third and fourth categories. As the participants in Category 2 focused on the purpose of engineering within Navajo life and its potential to provide economic stability, their experiences provided insight into the lack of engineering infrastructure in the Navajo community and the need for Navajo engineers to change the current state. For example, Nathan, a civil engineer, explained that there are limited opportunities for engineering jobs on the reservation:

> I think even though if you're educated, even if you get a degree, life on the reservations is not really conducive to engineering, if you know what I mean. . . . Then there's a few jobs that are available to engineers on the reservation but mostly it's off the reservation. There's got to be some sort of a change.

Gerald, an electrical engineer, also explained that there are limited STEM mentors for youth:

> While growing up a lot of young people wouldn't quite be told you're worthy, that you're valuable in some way so that I can invest in you and given that credibility and so bringing them to the understanding of what that is so they can actually continue and take that and make accomplishment after accomplishment.

A final insight into the tensions between Navajo community culture and engineering design and practice emphasized the stark differences between the nature of engineering work and Navajo sacred knowledge, including the Elders’ ways of knowing and living. This difference led to resistance to engineering from some Elders and families. On the reservation, according to the participants’ lived experiences, engineering work was viewed by some as favoring empirical Western knowledge systems and ignoring traditional teachings, such as respect for the Earth. This insight was found in Category 4 (Navajo-Centered Application), in which participants were focused on the tensions they experienced when applying engineering design and practice within a Navajo cultural framework. These insights illuminated the tensions between Navajo community culture and engineering design and practice, providing an understanding of lived realities as well as the opportunities to address the tensions. For example, Odin, a petroleum engineer, spoke of the resistance to engineering by some who choose a more traditional way of life:

> Some Navajos don't want the technology. Then I have relatives that don't speak English that live in a Hogan and don't have running water. They choose. . . . To give these people progress, even just running water and plumbing, you're going up against a brick wall, really. Why? Because it's in their belief that no, I don't need that stuff. I'm living just fine, and they do.

5.4 | Compatibilities between Navajo culture and engineering culture

As the Navajo engineers in this study represented a range of experiences with their local Navajo community, they also reflected a range of experiences concerning what it means to be an engineer and work within the field. The participants spoke of the ways in which engineering design and practice and Navajo community culture are compatible, providing examples of opportunities to further support engineering design and practice and its progress within a local community in ways that are grounded within the community’s ways of knowing and doing. For example, the Navajo community has had a long-standing tradition with the work that engineering seeks to accomplish. Although not labeled engineering within the community, Navajo peoples have relied on their imaginations and resourcefulness to improve their communities. This insight was realized through the participants’ experiences in Category 1 (Navajo-Centered Behavior) and was represented in the participants’ experiences in Categories 2, 3, and 4. The participants across all four categories recognized the resilience of the Navajo people and their abilities to design a new future for their community.

For example, Alden, a mechanical and electrical engineer, told the story about building his home with his wife and realizing how engineering has been a part of Navajo life and survival since before modern engineering:

> I think [engineering design], it's like always, always there whether we're, you know, growing crops, building, building our home. I think it wasn't, it wasn't until maybe we, my wife and I, had a wedding on the reservation that we're putting together, rebuilding Hogans and rebuilding shade houses for the Hogans, everything comes back together on the, the center of like the hexagon or octagon for the Hogan and we're building that center and it's, I started looking at it and I thought, "How, how is everything held together?" It all comes back to that basic center, center structure holding that whole building together. But it's you know up in the air; there's no, there's no supports holding it from the ground up. It's like load bearing all against that center, center position on the Hogan. So with
that we started looking at all our fancy tools we brought out to build and rebuild the Hogan and the whole roof area. And we're thinking, “How did they do it before without, you know without knowing all your different angles? What? How, how did they figure all that out?” But they did it. . . . Even with the farms there wasn't like a large, there's hardly any water under the reservation so how did they figure out how much water did they need to haul in?

Another insight was that the engineering and Navajo community cultures have many opportunities for compatibility and support for each other, but it will require Navajo engineers to explain engineering to their communities from a Navajo perspective. This insight was introduced in Category 3 (Navajo-Centered Strategy) and represented also in Category 4 (Navajo-Centered Application). The participants recognized the many overlaps between Navajo culture and engineering design and practice, and that their roles as Navajo engineers are instrumental in identifying and expanding those overlaps. For example, Bonnie, a renewable engineer who assists tribes with their energy planning, spoke about how her work requires her to explain engineering from a Navajo perspective:

*You know the type of work I do is technical assistance to tribes. [It is] all about how they might want to incorporate renewable energy so there's a lot of face to face. They have to, people who are, are trying to incorporate renewables need a good understanding. So I think part of my job is trying to explain things. . . . You help them understand the bigger impacts than just paying your electricity bill.*

Bonnie also explained that tribes have a philosophy that is compatible with the work that she is doing: “[be]cause tribes have that philosophy of trying to minimize impacts to their lands and maybe clean energy is an answer to that. So I see that connection now in what I do.”

The outcome space resulting from this study on the intersection of engineering design and practice and Navajo culture contributes to the current understanding of cultural border-crossing in engineering, and has implications for the development of culturally responsive engineering design curricula.

**6 | DISCUSSION**

The results of this study revealed four qualitatively different ways of experiencing the intersection between engineering design and practice and Navajo culture, specifically (a) designing using Navajo-centered behaviors, (b) designing with a Navajo-centered purpose, (c) designing using a Navajo-centered strategy, and (d) designing for a Navajo-centered application. The outcome space fills a gap in cross-cultural studies by contributing examples that are specific to experiences in engineering and the ways in which individuals experience crossing the borders between engineering design and practice and Navajo culture. Grounded in participants’ experiences, the outcome space also provides practical insights about the tensions and compatibilities between Navajo community culture and engineering design and practice as well as the value that Navajo community culture and engineering design and practice can bring each other. Looking toward culturally relevant pedagogy (Ladson-Billings, 1995) for engineering education, the outcome space can inform engineering curricula that are culturally relevant for Navajo students, derived from and grounded in the voices of Navajo engineers.

The current state of engineering education is failing many of our Native students. In a report for the Inter Tribal Council of Arizona, Moore and Lane (2014) wrote: “the majority of American Indian students are educated in a school system that doesn't appropriately value the community, culture, and Indigenous languages from which American Indian students come” (p.4). Engineering is likely no exception and may put Native students at risk for abandoning their Native culture due to the absence of home cultures in the processes of learning engineering and learning to think like engineers (Davis, 1998). The engineering education research community has an ethical imperative to examine the intersections between the culture of engineering and the cultures of communities, including Native communities.

As highlighted in this study, there are many intersections between the subculture of engineering and life-world subcultures of Navajo community culture, providing opportunities to transform engineering education. Within the border-crossing framework, Aikenhead (1996) describes two ways of crossing borders and boundaries of cultures: (a) assimilation, where disagreement between an individual's interpretation of local and mainstream culture creates tension and (b) enculturation, where agreement is found between an individual's interpretation of local and mainstream culture. Several categories of description discovered in this study highlighted assimilation-based tensions in the workplace. For example, in the Navajo-centered application category, one theme among participants was that they were stewards of sacred lands, recognizing the disconnect between what engineering practice expected of them and their obligations as a Navajo, but trying to do their jobs as engineers in the most culturally respectful way possible. However, in contrast, most categories of description in the outcome space were grounded in stories of
enculturation where Navajo engineers had found agreement with and advantages of their Navajo culture in the context of engineering. For example, in the Navajo-centered purpose category, participants spoke of using engineering to improve lives on the reservation and to provide economic stability for their families. Also pointing to enculturation across the categories of description, the Navajo engineers in the study recognized the value of local and mainstream cultures and how one can inform the other. The insights provided by the Navajo engineers' experiences included ways in which Navajo community culture can inform engineering, and vice versa. Specifically, the Navajo engineers across the categories indicated that Navajo community culture provides the knowledge base for ways of knowing and seeing the world. In this way, a knowledge base grounded in Navajo community culture can extend to engineering design work by providing new perspectives to engineering design and practice, such as consideration of the community and new strategies such as visual methods that are core to Navajo culture. Engineering design and practice, on the other hand, can broaden the Navajo community cultural knowledge base by adding scientific and analytical knowledge and skills. In this way, engineering design and practice can improve the quality of life for people on the reservation by improving infrastructure and income potential, and bridging local and mainstream community cultures.

Many questions remain to further understand intersections between engineering design and practice and Navajo culture. This study used a set of interview questions specifically crafted to examine the perspectives of Navajo engineers using a phenomenographic approach, specifically participants who pursued their degrees and were successful in becoming engineers. Furthermore, the participants were recruited in part from Native groups and professional organizations, indicating they had involvement in their home culture. There is a particular set of experiences that the engineering education community can learn from. However, additional perspectives of Native peoples are needed, such as those who failed to become engineers due to the grades required by universities and those who felt as though they had to abandon their Native culture for the sake of their professional identity. Just as there is a legacy of cross-cultural studies in science education, many additional studies are needed in the context of engineering for cross-cultural advancements. Phenomenographic methods offer tangible results that can be mapped to curriculum and affect community impact, just as they were done in this study (Jordan, 2015; Jordan et al., 2017; Jordan, Betoney, Pangan, Anderson, & Fernandez, 2018; Meadows et al., 2015).

The academy discourages individual expression of culture and alternative strategies for design that could be as or more successful than those taught in the classroom. The findings from this study suggest that when looking at engineering education through a border-crossing lens, we should design curriculum that actively promotes individual enculturation so that students of all cultural backgrounds can connect with engineering in a way that is uniquely theirs. By changing the conversation to empower our students to see how they as individuals can connect with engineering (e.g., through project-based learning, service learning, and new program criteria), we can improve the representation of underrepresented minorities in engineering. The results from this work should be examined through the framework of culturally relevant pedagogy (Ladson-Billings, 1995) to have implications for the future of engineering pedagogy. Native scholars have called for culturally relevant pedagogy for Native students as a way to further the progress of their communities (Castagno & Brayboy, 2008). Navajo communities have echoed this call and are working to further the cultural identity of their children and preserve their culture. Additional scholars continue to work toward these calls to identify the issues to be addressed in an effort to increase representation of Native American engineers (Kant, Thund, Burckhard, & Meyers, 2015). Illuminating the ways that Navajo engineers have experienced engineering design and practice as it intersects with their Navajo culture furthers the pathway toward culturally relevant engineering pedagogy.

7 CONCLUSIONS AND FUTURE WORK

Native Americans have been historically underrepresented in STEM fields, and little is known about how Native American engineers experience the cultural border-crossing between their Native culture and engineering design and practice culture. This study used a phenomenographic methodology to answer the research question: What are the ways in which Navajo engineers experience, understand, and apply engineering design and practice in the context of their culture and community? The map of the intersection of Navajo culture and engineering design and practice, built from the perspectives of Navajo engineers, advances new ideas and informs the engineering education community about connections between culture and engineering design and practice. The map of these connections, based upon the experiences of Navajo engineers, provides a foundation for the development of culturally responsive engineering design curricula for K-12 classrooms in the Navajo Nation (Jordan, 2015; Jordan et al., 2017; Jordan et al., 2018; Meadows et al., 2015). By designing engineering curricula through a lens of border-crossing, we can actively promote individual enculturation so that students of all cultural backgrounds can connect with engineering in a way that is uniquely theirs. Historically, the militaristic roots of the field of engineering emphasize how to monolithically think like an engineer by diminishing individuality. Culturally relevant pedagogy can act as a bridge to maintain rigor of the profession of engineering while promoting individual expression of culture as an asset.
The results of this study can inform educational innovations that have the potential to broaden the representation of Native American students in engineering. A key contribution of this work is to provide a foundation of knowledge of how Navajo engineers experience similarities and differences between Navajo culture and engineering design and practice. As the study population was entirely Navajo adult engineers, opportunities for future research include similar study of the intersection of Navajo culture and engineering design and practice from the perspectives of Navajo undergraduate engineering students and Navajo K-12 students who are learning the language of engineering design. The methodology from this study could be replicated in partnership with other Native American tribes to understand their cultural similarities and differences with engineering practice. Finally, the results of this study combined with similar studies of Navajo K-12 and undergraduate studies could be used to create a learning trajectory for K-12 curriculum that teaches Navajo culture and engineering design and practice side-by-side. Teaching engineering design and practice to K-12 students in a culturally responsive way could increase the number of Navajo students who choose to pursue higher education and careers in STEM fields.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1351728. We would like to thank the participants for sharing their stories with us and Dr. Kalvin White and the Office of Diné School Improvement staff in the Navajo Nation, without whom this study would not have been possible. We would also like to thank Dr. Shanna Daly, Dr. Gregory Light, and Dr. Llewellyn Mann for their phenomenographic expertise and support; Dr. Steven Semken for his guidance in the early stages of the study; Dr. Bryan Brayboy, Jacob Moore, and the Phoenix American Indian Science and Engineering Society (AISES) chapter for their help in recruiting participants; and Dr. Julie Martin and Dr. Alice Pawley for acting as critical peers. Finally, we would like to thank Navajo designers euniQue (euniquedesign.com, Instagram @euniqueink, Facebook + Twitter @euniquedesign) and Brian Skeet (bskeetdesign.com, Instagram @brianskeetdesign, Facebook + Twitter @bskeetdesign) for taking the outcome space to another level in the cover artwork.

REFERENCES

Adams, R., Daly, S. R., Mann, L. M., & Dall’Alba, G. (2011). Being a professional: Three lenses into design thinking, acting, and being. Design Studies, 32(6), 588–607. https://doi.org/10.1016/j.destud.2011.07.004
Aguilera-Black Bear, D., & Tippeconnic, J. W., III. (2015). Voices of resistance and renewal: Indigenous leadership in education. Norman, OK: University of Oklahoma Press.
Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. Studies in Science Education, 27(1), 1–52. https://doi.org/10.1080/0305726960856007
Aikenhead, G. S. (1997). Toward a first nations cross-cultural science and technology curriculum. Science Education, 81(2), 217–238. https://doi.org/10.1002/(sici)1098-237x(199704)81:2<217::aid-sce6>3.3.co;2-3
Aikenhead, G. S. (2001). Students' ease in crossing cultural borders into school science. Science Education, 85(2), 180–188. https://doi.org/10.1002/1098-237x(200103)85:2<180::aaid-sce50>3.0.co;2-1
Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. Journal of Research in Science Teaching, 36(3), 269–287. https://doi.org/10.1002/(sici)1098-2736(199903)36:3<269::aid-tea3>3.0.co;2-t
Åkerlind, G. (2005). Learning about phenomenography: Interviewing, data analysis and the qualitative research paradigm. In J. A. Bowden & P. Green (Eds.), Doing developmental phenomenography (pp. 63–74). Melbourne: RMIT University Press.
American Indian Higher Education Consortium. (2011). Living science: Strengthening and sharing Native knowledge at TCUs (p. 12) [NSF-AIHEC Summary]. Retrieved from American Indian Higher Education Consortium website https://www.aihec.org/our-stories/docs/reports/STEM-LivingScience.pdf
American Indian Higher Education Consortium. (2012). AIHEC AIMS fact book 2009–2010 (p. 52) [Tribal Colleges and Universities Report]. Retrieved from American Indian Higher Education Consortium website: https://www.aihec.org/our-stories/docs/reports/AMH_Consortium_Report_AIME_Report_Fact_Book.pdf
Backes, J. S. (1993). The American Indian high school dropout rate: A matter of style? Journal of American Indian Education, 32(3), 16–29.
Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. Science Education, 94(6), 1008–1026. https://doi.org/10.1002/sce.20392
Berryman, M., SooHoo, S., Nevin, A., Arani Barrett, T., Ford, T., Joy Nodelman, D., … Wilson, A. (2013). Culturally responsive methodologies at work in education settings. International Journal for Researcher Development, 4(2), 102–116.
Bowden, J. (2000). The nature of phenomenographic research. In J. Bowden & E. Walsh (Eds.), Phenomenography (pp. 1–18). Melbourne: RMIT University Press.
Bowden, J., & Marton, F. (1998). The university of learning: Beyond quality and competence. London, England: Kogan Page Ltd.
Bowden, J. A. (2005). Reflections on the phenomenographic team research process. In J. A. Bowden & P. Green (Eds.), Doing developmental phenomenography (pp. 11–31). Melbourne: RMIT University Press.
Brayboy, B. (2005). Toward a tribal critical race theory in education. The Urban Review, 37(5), 425–446.
University of Victoria Faculty of Human and Social Development. (2003). Protocols & principles for conducting research in an Indigenous context. Victoria, British Columbia, Canada: University of Victoria.

Vygotsky, L. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Walsh, E. (2000). Phenomenographic analysis of interview transcripts. In J. Bowden & E. Walsh (Eds.), Phenomenography (pp. 19–33). Melbourne: RMIT University Press.

Walther, J., Sochacka, N. W., & Kellam, N. N. (2013). Quality in interpretive engineering education research: Reflections on an example study. Journal of Engineering Education, 102(4), 626–659. https://doi.org/10.1002/jee.20029

Witherspoon, G. (1975). Navajo kinship and marriage. Chicago, IL: The University of Chicago Press.

AUTHOR BIOGRAPHIES

Shawn S. Jordan is an Associate Professor of Engineering in The Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, 7171 East Sonoran Arroyo Mall, Mesa, AZ, 85212; shawn.s.jordan@asu.edu

Chrissy H. Foster is a Postdoctoral Associate in Engineering Education in The Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, 7171 East Sonoran Arroyo Mall, Mesa, AZ, 85212; chrissyhfoster@gmail.com

Ieshya K. Anderson is a PhD student in the Engineering Education and Systems Design Program in The Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, 7171 East Sonoran Arroyo Mall, Mesa, AZ, 85212; ieshya.anderson@asu.edu

Courtney A. Betoney is a Manufacturing Engineer at Raytheon, New Mexico, 371 Frontage Road, Farmington, NM, 87401; aiden.cbetoney@gmail.com

Tyrine J. D. Pangan is a Management Intern in The Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, 7171 East Sonoran Arroyo Mall, Mesa, AZ, 85212; tyrinepangan@gmail.com

How to cite this article: Jordan SS, Foster CH, Anderson IK, Betoney CA, Pangan TJD. Learning from the experiences of Navajo engineers: Looking toward the development of a culturally responsive engineering curriculum. J Eng Educ. 2019;108:355–376. https://doi.org/10.1002/jee.20287

APPENDIX

TABLE A1 Full phenomenographic interview protocol (based on Daly et al. (2012))

| Section          | Questions                                                                 |
|------------------|--------------------------------------------------------------------------|
| Opening          | Structure and purpose of the interview                                    |
|                  | Interview logistics                                                      |
|                  | The goal of the research project is to create engineering design curriculum for middle school science classrooms on the Navajo Nation that teaches Navajo culture and engineering together. Our hope is that this curriculum will encourage more Navajo students to pursue higher education in science, technology, engineering, and math, and then use that knowledge to strengthen their local communities. To achieve the goals of this project, we need your help. We would like to interview you about your experiences with engineering as a Navajo engineer. Your interviews will be used to help design the engineering curriculum for Navajo middle schools. |
|                  | There are no right or wrong answers to any of the questions I ask you. I’ll ask follow-up questions so that we can arrive at a deeper understanding of your experiences. I’m going to leave some open time after I ask a question to give you time to think. Please ask if you have any questions or need me to clarify the question. |

(Continues)
| Section                        | Questions                                                                                                                                                                                                 |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| **Background and Definitions**| What does the word *engineering* mean to you?  
Are there any other words or phrases you might use to describe engineering?  
How would you describe engineering to a Navajo child?  
How would you describe engineering to a grandparent or Elder?  
How would you describe engineering to a peer who is not an engineer?  
How do you talk about engineering with your co-workers?  
How can engineering relate to your Navajo culture?  
Do you see engineering connecting with life on the Reservation?  
How does the way you think as a Navajo relate to the engineering design process?  
How would you help a young person connect to engineering?  
When did you decide to become an engineer and why?  
How do you exercise values from your culture as an engineer?  
Can you give me an example?  
How does that [insert value] relate to your culture?  
Do you think your co-workers share in a similar work philosophy?  
How does culture influence the way you perform the design process? |
| **Describing Experiences**    | Can you tell me about an experience you have had doing an engineering project?  
Have you ever designed or built something?  
What did that experience involve?  
What was the goal?  
What were you engineering?  
Who were you engineering it for?  
Where were you doing this engineering work?  
Who else was involved in this engineering experience?  
What was your specific role in the engineering? Please tell me about your responsibilities.  
Could you walk me through the [design] process that you use?  
What did you do?  
What led to that?  
Why did you do that?  
Did your approach change over the course of the project? How? Why?  
Did you learn anything new about engineering from your experience?  
Does your approach change depending on the engineering problem? How?  
How did culture influence the way that you worked on this project? |
| **Comparing Experiences**     | Can you describe another practical experience you have had that relates to engineering?  
How do you think this is different from the experience you talked about earlier?  
Did you use the same approach in this project as the previous one we discussed? |
| **Community**                 | How could engineering help you individually?  
What role would you say that engineering has in your life as a Navajo?  
How could you help your Navajo community with engineering?  
How could engineering help life on the Reservation?  
How could engineering negatively affect the community? |
| **Closing**                   | Are there ideas or recommendations you might have for engineering education in Navajo Nation schools?  
What advice would you give a child who has interest in engineering?  
Do you have anything else you want to add about engineering or Navajo culture, community, or society?  
Do you have any questions for me? |