

Latina/o Adolescents' Funds of Knowledge Related to Engineering

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Abstract

Background According to a growing body of research, many Latinas/os experience dissonance between their everyday cultural practices and the cultural practices prevalent in engineering. This dissonance contributes to many Latinas/os' sense that engineering is "not for me."

Purpose This study sought to explore the meaning in the relationship between engineering cultural practices and the funds of knowledge found in Latina/o adolescents' familial, community, and recreational settings.

Design/Method This ethnographic study followed seven groups of Latina/o adolescents as they identified problems in their communities and solved them through engineering design processes. Using a modified form of constant comparative analysis, we analyzed three data sources: individual interviews, observations of group meetings, and concurrent or retrospective protocols. We developed a coding scheme that categorized the participants' funds of knowledge as they related to engineering.

Results The participants' everyday skills and bodies of knowledge aligned with engineering practices. Specifically, their familial, community, and recreational funds of knowledge mapped onto the application of engineering design processes, systems thinking, ethical and empathetic reasoning, knowledge of production and processing, use of communication and construction tools, scientific and mathematical knowledge, and teamwork.

Conclusions Engineering instruction for Latina/o adolescents can be reconceptualized as a third space of learning and knowing where adolescents' everyday familial, community, and recreational practices are actively solicited and connected with the cultural practices of engineering.

Keywords design practice; student background; race/ethnicity

Introduction

Despite repeated calls for increased diversity in the engineering workforce (American Society for Engineering Education, 2014; National Academy of Engineering and National Research Council, 2009), Latinas/os remain profoundly underrepresented in this field (Landivar, 2013; National Science Board, 2014). According to Camacho and Lord (2013a), this problem is a

matter of recruitment rather than retention, because Latinas/os who matriculate into collegiate engineering programs persist at the same rate as their White counterparts (Lord et al., 2009). In short, many Latina/o adolescents opt out of engineering-related courses and careers before entering college (Gándara, 2006; Gilmartin, Li, & Aschbacher, 2006; Museum, Palmer, Davis, & Maramba, 2011). Consequently, educators and researchers need more research on how to present engineering as a rewarding and accessible endeavor to Latina/o adolescents.

Previous studies (Bouillion & Gomez, 2001; Celedón-Pattichis, Musanti, & Marshall, 2010; González, Andrade, Civil, & Moll, 2001; Upadhyay, 2006) found that K-12 teachers can draw from underrepresented students' everyday practices and bodies of knowledge in order to increase their understandings of science and mathematics. Comparable studies, though, have not been conducted in the field of engineering. Given that the number of K-12 engineering courses has proliferated over the last few decades (Carr, Bennett, & Strobel, 2012; National Academy of Engineering and National Research Council, 2009), and given that *Next Generation Science Standards* (NGSS Lead States, 2013) emphasize engineering, more research is needed to determine how teachers can integrate Latina/o adolescents' funds of knowledge with formal engineering practices. The purpose of this study was therefore to identify how Latina/o adolescents possessed engineering-related bodies of knowledge and skills derived from their everyday settings. The following section outlines a theoretical and empirical justification for pursuing this line of inquiry.

Funds of Knowledge and STEM Instruction

Engineering cultures are characterized by an "engineering way of thinking," "engineering way of doing," and "being an engineer" (Godfrey & Parker, 2010, p. 9). Many traditionally underrepresented students in undergraduate engineering programs often feel like they "don't belong," in part because their cultural practices and identities do not comport with those of engineering cultures (Chinn, 1999; Foor, Walden, & Trytten, 2007; McGee & Martin, 2011). For instance, Stevens, O'Connor, and Garrison (2005) described a Mexican American student who could not see how her identity as a "people person" was compatible with the more individualistic, competitive environment of her engineering program.

After interviewing Latina/o undergraduates who majored in science or engineering, Brown (2002) concluded that engineering instructors should establish cooperative learning groups, rather than perpetuate more traditional competitive environments, to increase Latina/o students' interest in science, technology, engineering, and mathematics (STEM) fields (cf. Martin, Simmons, & Yu, 2013). Pappamihel and Moreno (2011) argued that university professors often model behaviors and values that clash with those in many Latina/o families. They described Latina/o undergraduates who approached problems by seeking more information about their contexts and by obtaining multiple perspectives from different stakeholders, an approach that contrasted with their professors' emphasis on achieving direct and quick solutions.

To mitigate the discrepancies that many underrepresented students face between their familial practices and those in their STEM courses, several researchers (Buxton, 2006; Gutstein, Lipman, Hernandez, & de los Reyes, 1997) have called for instruction that incorporates students' home languages, familial and peer practices, and local community problems. Scholars have offered various visions for this type of instruction. Ladson-Billings (1995, 2009) argued for culturally relevant pedagogy that works toward social transformation and equity (cf. Riley, 2003), and Paris (2012) argued for culturally sustaining instruction that preserves heritage languages and practices (cf. Paris & Alim, 2014). Paris noted that terms such as "culturally relevant" and "culturally responsive" are not defined in consistent ways in

educational research literature, but scholars who use these differing terms share the belief that underrepresented students' cultural practices are assets to learning, rather than deficits or barriers. Teachers who actively value, solicit, and incorporate students' cultural practices enact "asset pedagogies."

Culturally responsive instruction (Banks & Banks, 2012) is not necessarily directed toward the preservation of heritage languages or societal transformation, but it shares similarities with other asset pedagogies in the sense that its goal is to connect underrepresented students' everyday bodies of knowledge, experiences, practices, and community concerns with the legitimized practices and bodies of knowledge that constitute academic disciplines, such as engineering. Several researchers (e.g., Barton & Tan, 2009; Moll, Amanti, Neff, & González, 1992; Moje et al., 2004) have offered frameworks that describe these everyday practices and bodies of knowledge related to science and mathematics.

This body of research has focused on funds of knowledge, defined as the knowledge, skills, and practices developed through historical and cultural interactions that enable individuals to function within their communities (Moll et al. 1992; Upadhyay, 2006). Early research in funds of knowledge (Moll, 1992; Vélez-Ibáñez & Greenberg, 1992) was conducted with families from Mexico in Southern Arizona. Later studies echoed earlier findings of funds of knowledge among Latina/o adolescents in Detroit, Michigan (Moje et al., 2004), urban adolescents in an immigrant Dominican and Puerto Rican neighborhood in the Northeastern United States (Barton & Tan, 2009), and among Puerto Rican households in New York City (Mercado, 2005). Despite being conducted in different locations, most studies of funds of knowledge have been conducted with working-class families (Rios-Aguilar, Kiyama, Gravitt, & Moll, 2011). Indeed, funds of knowledge are often "a matter of survival" to maintain families' well-being (Moll, 1992, p. 21). For example, funds of knowledge related to household maintenance are used by families to avoid expenses involved with hiring outside laborers or construction consulting services when something at home needs to be fixed.

Many funds of knowledge are intergenerational, accumulated from workplace and household management skills that have been handed down from grandparents and great-grandparents. These funds of knowledge include knowledge of carpentry, traditional remedies for illnesses, and methods of caring for animals and plants (Moll et al., 1992). Other funds of knowledge are contemporary and exchanged through extended family members and other social networks. These funds of knowledge include knowledge of current labor laws and knowledge of current market values of goods and services. Marshall and Toohey (2010) extended the notion of funds of knowledge by highlighting that such funds may also derive from interactions with a given culture's products and tools, such as music or video games that are shared within popular cultures.

Several studies (Barton & Tan, 2009; Moje et al., 2004) have confirmed that at least four types of funds of knowledge can enhance Latina/o adolescents' learning in science: family funds of knowledge, such as parents' work outside and inside of the home; community funds of knowledge, such as adolescents' community activism; peer funds of knowledge, such as recreation or play with friends; and popular cultural funds of knowledge, such as music and news media. Other research (González et al., 2001; Razfar, 2012) has connected Latina/o students' funds of knowledge to learning in mathematics. Civil (2002), for instance, described how Latina/o and Native American children, many of whom "were not among the most successful at mathematics as measured by school standards" (p. 145), accurately conducted complex mathematical calculations when their teacher structured an instructional unit around their parents' occupations in construction. As suggested by these studies, funds of

knowledge-driven mathematics and science instruction can increase the engagement and achievement levels of Latina/o students in STEM fields by building connections between scientific cultures and “the culture of their life-worlds” (Aikenhead & Jegede, 1999, p. 270) in a move toward culturally responsive instruction.

K-12 Engineering Instruction

Although these findings in mathematics and science funds of knowledge can inform engineering education, engineering is distinct from these disciplines in its goals, processes, and end products (Bybee, 2011). Unlike mathematics and science, a defining activity of engineering is design, defined as “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” (Dym et al., 2005, p. 104). In accordance with this emphasis on design, national K-12 engineering frameworks and standards (NGSS Lead States, 2013; International Technology Educators Association, 2007; National Assessment Governing Board, 2013) and numerous state standards (Carr et al., 2012) emphasize design processes, including iterative applications of problem scoping, generating and evaluating ideas, and communicating solutions. One purpose of this study, therefore, was to identify research participants’ funds of knowledge related to engineering design processes.

Sneider and Rosen (2009) argued that K-12 education should also include instruction in three engineering-related domains: knowledge, skills, and habits of mind. Accordingly, we also sought to identify the participants’ engineering-related funds of knowledge in these three domains. Engineering knowledge includes a knowledge of scientific and mathematical principles and knowledge of production and processing, such as knowing how “a series of actions or steps [are] taken to achieve a desired end” (Moore et al., 2014, p. 6). Engineering skills include the ability to work well in teams and to use a variety of tools and materials, ranging from information and communication technologies to calipers (Moore et al., 2014; National Assessment Governing Board, 2013). Finally, engineering habits of mind include systems thinking, or the ability to consider how changes within a technological subsystem affect that subsystem and the surrounding environment and society (National Assessment Governing Board, 2013), and empathy, or “the ability to understand what another person is experiencing from within the frame of reference of that other person” (Strobel, Hess, Pan, & Morris, 2013, p. 139; cf. Rasool, Danielsson, & Junger, 2012). Although the bodies of knowledge, skills, and habits of mind outlined here are not intended to be exhaustive, they represent prominent themes across K-12 engineering education literature.

Toward third space in K-12 engineering instruction Asset pedagogies support students in developing the bodies of knowledge, skills, and habits of mind associated with different academic disciplines, but their ultimate purpose is not to simply reproduce these disciplines, many of which seem alienating to underrepresented adolescents (Rodriguez, 2013). The National Academy of Engineering (NAE, 2008) confirmed that traditional definitions of engineering – such as that engineering is applied science and mathematics – dissuade many Latina/o adolescents from pursuing careers in this field. The NAE recommended that K-12 teachers and other stakeholders should instead emphasize the “real-world applications” of engineering, such as how engineering has “a direct and positive effect on people’s everyday lives” (p. 5). This recommendation aligns well with culturally responsive STEM education, whose purpose is to build connections between STEM practices and the everyday lives of students.

The concept of third space has been used to theorize how teachers and students can build these connections. Soja (1996; cf. Bhabha, 1994) used the term *third space* to refer to a space wherein persons are not faced with an either-or choice between potentially contradictory practices and worldviews, but instead can combine “both-and-also” in ways that generate new ideas and hybrid practices (p. 5). Although Soja did not apply this term to STEM instruction, later scholars (Moje et al., 2004; Seiler, 2013; Wallace, 2004) used the term to describe how the first space of students’ everyday experiences and cultural practices can be combined with the second space of scientific cultures and practices. In the resultant hybrid space, or third space, the end goal is not to reproduce the status quo in science. Rather, the end goal is to produce a new, hybrid creation in which students’ everyday practices, bodies of knowledge, skills, and habits of mind are integrated with formal scientific practices, bodies of knowledge, skills, and habits of mind.

According to Barton and Tan (2009), science instruction that is informed by third-space theory includes three dimensions: a political dimension, a geographic dimension, and a pedagogical dimension. In the political dimension (cf. Gutiérrez, Baquedano-López, & Tejada, 1999), power is shared between students and teachers when students are positioned as experts and decision makers. In the geographic dimension, teachers and students blur the physical boundaries separating schools and households. In practice, students often share objects from their homes and from places in their communities, or they conduct investigations regarding problems in their neighborhoods (cf. Bouillion & Gomez, 2001). In the geographic dimension, the physical appearance of the classroom may also change in different ways, such as when student desks face toward each other rather than toward the teacher.

In the pedagogical dimension, teachers use relevance to students’ lives as the starting point, rather than state or national standards as the starting point. Teachers first ascertain students’ concerns and interests, then weave them with formal STEM practices, bodies of knowledge, skills, and habits of mind. Funds of knowledge are central to third-space instruction across all three dimensions. They enable students to blur the physical boundaries between school and community when objects in the classroom, such as the devices that they seek to improve or the tools they use to improve them, incorporate or mimic the objects from their households or neighborhoods. Third-space instruction challenges traditional political configurations in the classroom by recognizing students’ expertise in their funds of knowledge, and they incorporate pedagogical dimensions by showing relevance between everyday lives and engineering.

Research Questions

Because many definitions of third-space instruction are grounded in funds of knowledge (e.g., Barton & Tan, 2009; Moje et al., 2004), we sought to develop a framework of funds of knowledge that connects to engineering design. To this end, we invited 25 Latina/o adolescents, ages 14 to 17, to work in teams to engage in projects where they identified problems in their communities that could be solved through engineering. We followed them over the course of one academic year as they developed these projects. Our initial inquiry was guided by one research question: What funds of knowledge did the participants apply as they developed solutions to their self-selected problems? During our initial interviews with them, we learned that they addressed many engineering-related problems outside of the scope of their self-selected projects. Consequently, we developed a second research question: What engineering-related funds of knowledge did the participants apply as they developed solutions to other problems in their lives?

Method

Our research methods aligned with constructivist traditions of qualitative inquiry, in which researchers seek to understand and describe a contextualized phenomenon (Lather, 2007). Constructivist research is based on the epistemological assumption that participants' understandings, experiences, and standpoints form the basis upon which knowledge is constructed (Creswell, 2007). By implication, researchers must develop robust understandings of participants' perspectives, and they must rely on emergent designs in which protocols are modified in dialogue with participants and others who hold these perspectives (Koro-Ljungberg & Douglas, 2008). In accordance with the constructivist paradigm, we used an ethnographic approach to data collection and analysis (Hammersley & Atkinson, 2007; Moll et al., 1992).

Recruitment and Selection

We recruited 10 research participants in September 2012 and an additional 15 participants in September 2013. The participants remained in the study for nine months, or one school year, until they completed their projects in June or July. To recruit participants, we visited meetings hosted by organizations, such as Latinos in Action, which emphasized civic engagement for Latina/o adolescents. In our recruitment speeches, we explained that participants would meet in groups twice per month after school to identify problems in their communities that could be solved through engineering. In accordance with the National Academy of Engineering's (2008) recommendation, we emphasized that participants would have the opportunity to make a difference through engineering. To enable the participants to work on project-related tasks from their homes, we offered each of them a notebook, a tablet computer, and wireless Internet access in their homes for the duration of the project. Finally, we stated that participants would receive \$300 for participating, \$150 in January and \$150 in July, regardless of the outcome of their project.

During the recruitment sessions, we distributed English and Spanish consent forms that had been approved by an institutional review board. Over 60 Latina/o adolescents and their parents or guardians signed and returned the forms. From this pool of potential participants, we selected 25 on the basis of two criteria: native Spanish fluency and recent enrollment in English as a Second Language (ESL) courses. We developed these criteria because ESL students are more underrepresented in advanced STEM courses and professions in the United States than native English speakers (Gándara, 2006; Lee, 2005), and we sought to work with underrepresented adolescents.

Participants

At the time of the study, the participants attended high schools in the rural Western United States. Seventeen participants lived with at least one parent or guardian who was born in Mexico; of these participants, nine had lived in Mexico themselves. The other participants or their parents were immigrants from El Salvador, Honduras, or Guatemala. All participants stated they wanted to participate in the study for one of three reasons: to give engineering a chance as a potential career choice, to provide service to their communities, or to increase their chances of getting accepted to the best college possible by increasing their participation in co-curricular activities.

Most of the participants had limited experience with engineering prior to participating in this study. Although seven of them had taken required introductory engineering courses at

their high school, they described the content of these courses as using drafting software to produce models of solid geometric objects, rather than as applying design processes to address real-world problems. In final member checks, or conversations with the participants in which we asked them to provide feedback on the results from the study, the participants confirmed our perception that they rarely or never drew from the content of these engineering courses to solve their self-selected problems. They relied more heavily on their funds of knowledge.

Groups and Projects

We placed the participants into groups according to three criteria: participants' proximity to their homes in relation to one another, desire to work on similar problems, and indication that they wanted to work with specific individuals. Table 1 lists the groups that we formed, the participants' self-selected problems, and the outcomes of their projects. We formed five same-sex groups because several girls wanted to work with other girls, and several boys wanted to work with other boys. Through this grouping method, we intended to provide the participants with a safe environment in which to interact with one another, thereby encouraging them to remain in the study for its duration. Only one participant, Carisa, withdrew because she was deported to her native country.

Table 1 Description of Groups and Projects

Group	Group composition	Self-selected problem	Outcomes of the project
1	Eduardo (male, 16) Federico (male, 17) Miguel (male, 16)	Design a user-friendly door for people in wheelchairs at their high school.	Produced visual model; gave presentation to high school administrators and custodians.
2	Eva (female, 16) Laura (female, 17) Mateo (male, 15)	Improve and expand a local playground to increase attendance.	Produced visual model; shared PowerPoint presentation with local city council and a civil engineer.
3	Ana (female, 16) Noemi (female, 17) Silvia (female, 15) Zoe (female, 17)	Improve an existing device used by veterinarians to restrain feral cats as they receive vaccination shots.	Produced visual model; mailed a letter to the company that sold the existing cat-nabber.
4	Emiliano (male, 17) Patricio (male, 14) Samuel (male, 16)	Improve existing water- and cold-resistant shoe for running and playing in the snow.	Produced visual model; sent an email to the company that sold the existing shoe.
5	Alisa (female, 15) Carisa (female, 14) Carla (female, 15) Paula (female, 16)	Improve water catchment systems for individual homes in rainy regions of Honduras.	Produced visual model; emailed a PowerPoint presentation to a representative of a nonprofit charity concerned with water issues.
6	Carmen (female, 17) Dulce (female, 17) Felicia (female, 16) Katie (female, 16)	Improve existing playground swing for children in wheelchairs.	Printed a three-dimensional model; shared a PowerPoint presentation with the head of their city's Parks and Recreation Department.
7	Claudia (female, 17) Seina (female, 16) Sofía (female, 17) Tomás (male, 17)	Improve head rests on tub-based shower chairs for children with disabilities who cannot hold up their heads.	Printed a three-dimensional model and constructed a physical prototype of the design; gave the prototype and a PowerPoint presentation to the caregiver of a boy who used a tub-based shower chair.

Note. All names are pseudonyms.

Throughout the study, we provided minimal instruction in engineering because we wanted to observe how the participants applied their own funds of knowledge to solve problems. At the initial group meeting, we presented a variety of problems that were typical in different branches of engineering (e.g., McNeil, 2013; Tucker, 2012). We then referred the participants to an educational website that guided them through the process of designing a cell phone for elderly clients and that provided them with feedback on their designs (EdHeads, 2014). The participants identified how this activity incorporated elements of the engineering design cycle (NGSS Lead States, 2013). After this initial meeting, we did not provide additional instruction in engineering although we periodically asked the participants to reflect on their work and identify which stage of the design cycle they thought they were enacting. At the end of the study, the groups selected an audience to which they presented their designs (see Table 1).

Research Team

The authors came to this study with a range of expertise. The first author, a specialist in culturally responsive education with a certificate in qualitative research, was raised in the area where the study was conducted. The second and third authors hold master's degrees in metallurgical and environmental engineering and were raised in Mexico and the Dominican Republic, respectively. The first, second, and third authors co-facilitated bimonthly group meetings, and they interviewed participants in English or Spanish. Their geographic and cultural similarities with the participants helped to build *confianza*, or trust, throughout the research process (Moll et al., 1992). The first three authors analyzed the data, while the fourth author, a bicultural specialist in funds of knowledge and ways of knowing, advised the development of the analytic codes and the manuscript.

Data Collection

We collected four types of data to ascertain the participants' engineering-related funds of knowledge. First, we collected copies of participant-generated artifacts, such as sketches in the participants' notebooks and photographs that the participants had taken of objects they built. We did not formally analyze these data, but we used them as starting points to determine whether and how they drew from particular funds of knowledge. For example, we asked Samuel to explain what he was thinking while he drew the tread for a sole's shoe. We found that, while he was drawing, he recalled his previous experiences with playing soccer on various surfaces while wearing cleats. In this example and others, we could not determine the participants' funds of knowledge by viewing their artifacts, but their verbal explanations, offered during or after the creation of the artifacts, often indicated the funds of knowledge they applied.

Second, we conducted monthly individual interviews, ranging from 30 to 60 minutes, with each participant. In introductory interviews, we sought to ascertain general funds of knowledge that were relevant to engineering (Appendix A). These interviews revealed engineering-related funds of knowledge that the participants applied to various problems in their lives. In ongoing interviews, we asked questions about how they applied these funds of knowledge to their self-selected projects (Appendix B).

Although Appendixes A and B give the baseline questions that we asked all participants, we developed additional interview questions for each individual in accordance with the principles of emergent research design (Rubin & Rubin, 2012). Soon after we received written transcripts from the interviews and group meetings, we read them to identify instances in which we were confused or wanted more information, and we developed specific interview questions to clarify or extend previous comments. For instance, one participant in Group 7,

which sought to improve a shower chair headrest, mentioned that she helped her grandmother when she provided home and hospice care to the elderly. We later asked her to “please describe a time you helped your grandmother care for the elderly,” under the assumption that her response might have indicated experiences with modifying devices or processes to meet the needs of people with disabilities.

Third, we collected data from two retrospective or concurrent think-aloud protocols from each participant as they conducted tasks that we believed might be relevant to engineering or as they conducted a task relevant to their self-selected projects. Think-aloud protocols provide windows into participants’ thoughts as they verbally articulate what they are thinking while they are engaging in a task (concurrent protocol) or articulate what they thought as they engaged in a past task (Ericsson & Simon, 1993; Gero & Tang, 2001). In an introductory interview, for example, one participant mentioned that he played with an app in which he designed, tested, and redesigned apple carts. Later, in a concurrent protocol, he thought aloud for us while playing with this app. These think-alouds enabled us to observe how the participants applied engineering-related skills and bodies of knowledge to everyday tasks as well as to their self-selected projects.

Fourth, we facilitated bimonthly group meetings in which the participants identified problems in their communities and developed solutions to them. As with the interviews, the protocols to lead these meetings were modified in response to the needs of the research participants (Manning, 1997). For instance, we noticed that several participants had forgotten the conclusions they reached in their previous group meetings, and they described themselves as “stuck.” Consequently, we began future group meetings by asking the participants to summarize what they did in the last meeting and to set goals for the present meeting. Throughout all meetings, our goal was to ask open-ended questions that would help the participants advance in the design process (Appendix C). During these meetings, the participants’ comments often indicated that they drew from their funds of knowledge to produce their solutions, such as when Zoe cited her experiences with volunteering at an animal shelter to convince her group that they should adopt a specific solution element for their improved catnabber, a device designed to restrain feral cats.

Data Analysis

We used a modified form of constant comparative analysis (Corbin & Strauss, 2014) to analyze transcripts from the individual interviews, from the retrospective and concurrent protocols, and from the bimonthly group meetings. Constant comparative analysis uses the dual “analytic strategies of asking questions and making comparisons” (Corbin & Strauss, 2014, p. 199) to determine patterns in the data. According to this coding method, researchers notice similarities across multiple data points and develop definitions, or codes, that identify the commonalities across those data points. Though constant comparative analysis has historically been associated with grounded theory, an approach to data analysis in which all codes are developed inductively from the data, several scholars (Miles & Huberman, 1994; Smagorinsky, 2008) have argued that scholars can apply preexisting codes from previous research or theoretical literature to new datasets.

Acting under this latter assumption, we read theoretical and empirical literature related to three areas: Latina/o adolescents’ science-related funds of knowledge (Barton & Tan, 2009; Moje et al., 2004); engineering design processes (Atman et al., 2007); and engineering bodies of knowledge, skills, and habits of mind (International Technology and Engineering Educators Association, 2007; Moore et al., 2014). Informed by this literature, the first and second

authors developed a preliminary set of preexisting codes in each of these areas. We then read through randomly selected data points and discussed the extent to which these preexisting codes should be modified or expanded to more accurately describe the features of the data from this particular study. We developed a modified list of codes (see Tables 2 to 4) that more accurately reflected the features of the current dataset. The following example will illustrate an example of how we modified a code from a previous study.

Moje et al. (2004), in their study of Latina/o adolescents' science-related funds of knowledge, developed a family funds of knowledge code, which they assigned to science-related bodies of knowledge and practices that Latina/o adolescents learned from family members. They identified "environment and health funds" as a subordinate code under this larger family funds of knowledge code, and they defined this subordinate code as "environmental problems in [participants'] home countries or places of origin in the United States, as well in their current community" (p. 54). These environmental problems affected the adolescent participants' health. Informed by this preexisting code, we noticed while reading transcripts that many participants cited family members' health problems when discussing their engineering projects.

In contrast to Moje et al. (2004), who defined health in relation to environmental factors such as air pollution, we found that our participants referred to physical disabilities or injuries, but they did not refer to the environment. Hence, we modified the title of this code, which was originally "environmental and health funds" to "health of self and family." We defined this code as "funds of knowledge acquired from managing one's own health or the health of family members who have disabilities, illnesses, or injuries."

Using this method of coding, in which we modified pre-existing categories based on patterns that emerged from the data, we developed three coding schemes: one related to funds of knowledge (Table 2), one related to engineering design processes (Table 3), and one related to engineering bodies of knowledge, skills, and habits of mind (Table 4). The first and second authors applied these codes to one think-aloud or interview transcript from each participant and one transcript from a group meeting for each group. Because no new codes emerged, we assumed that saturation had been reached, or that no additional funds of knowledge, engineering design processes, or engineering bodies of knowledge, skills, and habits of mind were present in the dataset.

The third author and two external advisors evaluated randomly selected examples of coded data and confirmed the accuracy of the codes, but they suggested changes in phrasing for four codes. Using codes that incorporated their suggestions, the first and second authors independently coded 10% of the randomly selected data and achieved 92% agreement. The second author coded the remainder of the dataset, from which we selected "telling cases" (Mitchell, 1983) to report in the Findings section. We selected these cases according to three considerations. First, each case represented a different code related to funds of knowledge (Table 2). Second, the cases collectively represented all codes related to engineering (Tables 3 and 4). Third, the cases were information rich in the sense that the participants elaborated more in their responses regarding these cases (Patton, 2014).

Ensuring Research Quality

We ensured that our methodology met standards of evidence for qualitative research (Freeman, deMarras, Preissle, Roulston, & St. Pierre, 2007) during two stages: the "making" of the data and the "handling" of the data (Walther, Sochacka, & Kellam, 2013). To ensure quality during the first stage, the first author provided professional development on data collection methods (Walther et al., 2013) to the second and third authors, who were graduate

Table 2 Coding Scheme of Engineering-Related Funds of Knowledge

Code	Definition	Example
Family funds of knowledge		
Workplace	Funds of knowledge acquired from family members who taught workplace skills or who provided opportunities to learn on the job.	Noemi's father taught her how to maximize efficiency when transporting chickens at their shared workplace.
Health of self and family	Funds of knowledge acquired from managing one's own health or the health of family members who have disabilities, illnesses, or injuries.	As a primary caregiver for his younger brother who had a degenerative muscular disease, Tomás learned how to view devices from the perspective of users with disabilities.
Transnationalism	Funds of knowledge acquired from living, visiting, or communicating with family members in other countries.	Drawing from her experiences with visiting her grandmother in Mexico, Claudia explained why fences around many homes in Mexico City needed to be different than fences around farms in the region in which she currently lived.
Household management	Funds of knowledge acquired from maintaining an apartment, home, or yard.	Seina worked within economic and material constraints to conceptualize and build a chicken coop in her yard.
Community funds of knowledge		
Volunteerism	Funds of knowledge acquired from providing service to the community.	While volunteering at a retirement center, Seina learned scientific principles related to epidemiology when she prevented the spread of infectious diseases.
Community organizations	Funds of knowledge acquired from participation in a local community organization, such as a club or church group.	While participating in Boy Scouts, Miguel and Federico worked within material constraints to conceptualize and build devices for cooking over a campfire.
Recreational funds of knowledge		
Sports	Funds of knowledge acquired from participating in sports, from following professional sports teams, or from reading and viewing sports-related information.	Patricio learned the rationale behind sports shoe designs from reading soccer fan sites, from listening to his soccer coach, and from evaluating shoes in conversations with other soccer players.
Popular culture and digital technologies	Funds of knowledge acquired from viewing mass media, reading popular cultural texts, or interacting with digital technologies.	While playing the popular computer game <i>Age of Empires</i> , Miguel decided which materials he should use to build fences and later evaluated his selection of materials based on how well they repelled invaders and on how long they lasted.

students at the time of the study. During weekly team meetings, we read transcripts from the study and collectively annotated them while critiquing our data-collection techniques. A fourth colleague played devil's advocate during these team debriefings by reading the transcripts and pointing out possible weaknesses in our data-collection methods (Erlandson,

Table 3 Coding Scheme Related to Engineering Design Processes

Code	Definition	Example
Problem definition	Identify a need, problem, or want; identify areas for improvement of current devices or systems; identify audience for product; or identify criteria and constraints.	Specify that the shoe must be easy for people to secure even if they are wearing winter gloves; must keep feet warm; and must repel snowwater.
Information gathering	Consult others regarding aspects of the problem; look for information on the Internet; or observe, manipulate, or test existing devices or systems to determine areas for improvement.	Distribute surveys at local library and park to determine the types of changes that people in the community would like to see made to the local playground.
Idea generation	Generate potential solutions to part or all of the problem(s); or identify possible steps that the team needs to take in order to solve the problem or produce the design.	Suggest marine vinyl as the lining for the shower chair headrest in order to meet the criterion that it must repel water.
Modeling	Sketch and label representations of ideas; use mathematics to calculate different aspects of the design; or build a physical prototype.	Draw a proposed wheelchair swing whose measurements are informed by measurements of existing swing set.
Feasibility analysis or evaluation	Determine whether the design is workable; evaluate an idea or solution element based on one or more criteria or constraints; weigh competing criteria and constraints and consider trade-offs in attempts to optimize design; evaluate solution elements based on physical or virtual tests.	State that a detachable headrest might make the shower chair easier to transport in small cars and easier to replace if the head rest wears out, but the client might lose a detachable head rest if she or he took it off, and detachable parts might make the overall device more complicated to assemble.
Realization of solution	Construct or improve an existing physical device or product; implement a series of processes that solves a problem or meets a need; or select a solution or solution element.	Build a mud oven out of available materials in order to enable the family to prepare tamales for a food stand.

Harris, Skipper, & Allen, 1993). External advisors with expertise in funds of knowledge or engineering education also evaluated our early transcripts and provided feedback on how we might improve our protocol instruments (Appendixes A to C) and our interviewing techniques. On the basis of this feedback, we modified our data collection protocols and approaches as described above.

To further ensure quality during the data-collection phase, we triangulated data across multiple sources over a prolonged period of time (Maxwell, 2005). For example, if a participant made a comment during a group meeting that suggested the application of a type of fund of knowledge, we obtained more information by individually interviewing the participant about that comment. As a second example, if the introductory interview indicated that a participant applied particular funds of knowledge to a problem in her life, we sought to obtain more information about her process of solving that problem through a retrospective protocol.

Table 4 Coding Scheme Related to Engineering Bodies of Knowledge, Skills, and Habits of Mind

Code	Definition	Example
Scientific or mathematical knowledge	Apply knowledge of scientific or mathematical facts or principles to a problem.	Explain how diseases can be transmitted from cat to cat, and use this knowledge to suggest a cat-nabber design that is easy to sterilize.
Systems thinking	Consider multiple interconnected variables, including social, physical, economic, and temporal variables; analyze how changes to one variable might influence other aspects of the system.	Identify how poverty in some areas of Honduras can adversely affect a region's overall water supply when those who cannot afford toilets dump waste into a river that is later used as a water source.
Production and processing	Apply knowledge of materials; costs; and sequential acquisition processes, production processes, or distribution processes in order to maximize efficiency in the creation or distribution of a product or the implementation of a process, or in order to maximize profits gained from a product.	Decide to buy more expensive manufacturing equipment because it will produce perfume 50% faster than cheaper equipment, ultimately leading to greater profits in the long run (while playing with a retail applet).
Ethical considerations and empathy	Demonstrate a commitment to the well-being of animals, the environment, or vulnerable human populations; consider a product or system's impact from the perspective of somebody living under different conditions than oneself.	Assert that certain shower chair materials would feel uncomfortable to people who need assistance with entering and existing the bathtub, based on prior experience with giving showers to the elderly at a retirement home.
Use of tools	Use communication tools to generate or communicate design ideas; use measuring tools; explain how construction tools are used to produce or install a design.	Use Adobe Illustrator TM , a commercial vector graphics editor, to produce visual of proposed design.
Teamwork	Divide roles based on individuals' expertise or characteristics in order to efficiently complete a project and to reach a common goal.	Assign more difficult food preparation roles to more experienced members of a team when running a food stand.

We also ensured quality by collecting data until theoretical saturation had been reached (Glaser & Strauss, 1967; Walker, 2012). To achieve this level of quality, we began data analysis while we were still collecting data. We collected data in two nine-month periods, working with Groups 1 to 3 during the first nine months and Groups 4 to 7 during the second nine months. By the end of the second data-collection period, no new codes emerged. This absence of codes indicated that we no longer needed to collect additional data.

We also took measures to ensure quality as we handled the data. To establish quality in the data analysis process, multiple persons, including the four authors and external advisors, confirmed they saw the same phenomena in the data (Lincoln & Guba, 1985). We ensured that two coders independently identified the same phenomena in the data and achieved over

85% agreement in their application of codes (Saldaña, 2012). Finally, after the data had been collected and analyzed, we shared our findings with the research participants (Lindlof & Taylor, 2002). They confirmed that the analysis was a fair representation of their experience, although they stated that they did not know during the time of their projects that they held funds of knowledge relevant to engineering.

Limitations

Because our data-collection instruments focused primarily on funds of knowledge, we may not have ascertained other forms of knowledge learned through participants' science and mathematics classes. Pawley (2009) found that many professionals largely define engineering as the application of codified scientific and mathematical principles. By omitting questions related to these principles in our protocols, we were unable to ascertain whether the participants engaged in activities that have traditionally been recognized as engineering.

Furthermore, it is problematic to apply the term *Latina/o* to culturally and geographically diverse adolescents (Camacho & Lord, 2013b; Gándara & Contreras, 2009). We used this term because 24 out of 25 participants used it to describe themselves and because they or their ancestors were from Latin America. Although common types of funds of knowledge, such as family funds of knowledge derived from parents' workplaces, have been found to exist among diverse *Latina/o* adolescents who live in urban and rural areas (e.g., Mercado, 2005; Moll et al., 1992), our methodology did not enable us to determine many nuances in funds of knowledge, such as whether parents from Mexico City taught their children a different set of workplace-derived skills than parents from rural Honduras.

Findings

Although we developed three coding schemes, the findings are organized according to the first coding scheme in which we identified the participants' engineering-related funds of knowledge (Table 2). The Findings section is divided into eight subsections, each of which align with a code from Table 2: workplace, health, transnationalism, and household management (codes related to family funds of knowledge); volunteerism and community organizations (codes related to community funds of knowledge); and sports and popular culture and digital technologies (codes related to recreational funds of knowledge). In each subsection, we describe how the participants' funds of knowledge in that area included the application of engineering design processes (Table 3) or how their funds of knowledge included engineering bodies of knowledge, skills, and habits of mind (Table 4). We organized our findings according to funds of knowledge, rather than according to engineering design processes and skills, to reflect our belief that students' funds of knowledge should be the starting point for engineering education, as opposed to traditional forms of engineering education that have privileged formal engineering practices above students' funds of knowledge (Riley, 2003). In accordance with our two research questions, in each subsection we describe how the participants applied their engineering-related funds of knowledge in one of two ways: to their group projects, or to other problems in their everyday lives.

Workplace

Twenty-two participants' parents held working class jobs, such as packaging meats or plastics, transporting chickens, and mowing lawns. The participants often helped their parents at work,

and 14 of them also held jobs of their own. While at the workplace, they gained experience with solving problems through applying engineering-related processes and habits of mind. For example, Federico and Miguel worked with their fathers at a small dairy farm. Their employers were concerned with the high bacteria counts in the cows' milk because corporate buyers gave them more money for milk with less bacteria. The farm's current solutions – washing the cows with warm water and testing their milk once per month – were not achieving target bacteria counts.

To solve this problem, Federico “started telling them [his employers] different ways to improve,” including placing black mats under the cows so workers could see more clearly whether the milk appeared to be thicker than normal (one indication of mastitis), in which case they would stop adding the cow's milk to the overall supply. He also observed,

I know they use [milking] cups where they're hooked up to the cow, and they don't replace those very often, so I started telling them to replace them every two months. . . . I've noticed the other guys, they get manure on the gloves, and they just start putting them on [the cups on the cows' udders], so they're dirty.

In addition to suggesting that the management periodically replace the milking cups, he also trained new workers on how to prevent bacteria from entering the milk supply by teaching them to detect mastitis and to wash their gloves frequently. Lastly, he suggested that his employers clean the machines, place higher-quality filters on them, and keep the cows' diet and feeding times consistent in order to promote the cows' health. By following Federico's suggestions, his employers decreased the milk's bacteria count by 30%.

Federico's activities in the workplace gave him practice with elements of engineering design processes. He gathered information by determining what constituted acceptable levels of bacteria in milk for human consumption, as set by federal regulations. He defined the problem as he articulated criteria and constraints for a successful solution, such as that the solution must meet standards for bacteria counts and must be inexpensive. He further defined the problem through close observation and analysis of the workings on the farm. He noticed, for example, some cows exhibited signs of illness weeks before the formal monthly mastitis tests were given, and consequently milk with unhealthy bacteria counts entered the supply. He also noticed that coworkers with manure on their gloves placed milking equipment on the cows. From these observations, he knew which components of the milking equipment were likely to be covered in manure and thus transmit infection.

After collecting these types of data, Federico generated multiple ideas to solve the problem, and he iteratively evaluated his proposed solutions after his employers told him how high the bacteria count was for each batch of milk after they had tried each of his suggestions. Finally, he engaged in systems thinking when he proposed a multidimensional solution that accounted for interacting elements – such as the cows' diet, human behavior, and the maintenance of the machines – rather than suggesting a one-dimensional solution, such as simply purchasing an improved filter. In this sense, Federico's workplace provided him with opportunities to define complex problems and to develop and evaluate solutions to those problems. These practices are central to engineering (Atman et al., 2007).

Felicia also developed engineering-related funds of knowledge through her workplace. She and her family previously ran a successful roadside food stand in Mexico. She described how her brother repurposed an antique *chaca-chaca* (washing machine) by lining it with *barro* (clay), and her mother used it as an oven to prepare tacos and enchiladas. Felicia, her mother, and her younger sister regularly prepared food by drying chilies, soaking carrots in vinegar,

dicing and boiling potatoes, chopping cabbages and onions, grating cheese, and killing and frying chickens. Dozens of people who lived “pretty far would come all the way to our house to eat there” each day. To meet this high demand, Felicia’s family discussed and applied numerous strategies to improve efficiency. These solutions included taking their daily personal showers between precisely timed and sequenced food preparation activities so they could ensure their food stand would open at peak times with hot, fresh food.

To further improve efficiency, the family divided labor according to each member’s strengths. Her younger sister served drinks because she was too young to safely handle food next to hot surfaces. Because the potatoes had to be diced quickly but precisely in order for them to reach the right consistency during the allotted boiling time, Felicia’s skilled and experienced mother cut the potatoes. Felicia was assigned other tasks that required less precision and that took less time, such as grating carrots. From this experience, Felicia learned skills related to production and processing as her family sought to maximize the volume and quality of food produced during lunch and dinner. Felicia learned how to achieve efficiency through the strategic management of resources such as time, human labor, and available equipment. She also gained teamwork skills by working with others to achieve a common goal while capitalizing on the team members’ strengths.

Health of Self and Family

All of the participants had at least one family member who had been moderately to severely injured, and these injuries fostered the participants’ sense of ethical considerations in engineering. Sara, for example, described how her father sustained injuries after decades of lifting cow carcasses onto meat hooks. According to Sara, her dad’s employers were unwilling to purchase adequate safety mechanisms because “what they want is to gain more money,” and purchasing additional safety mechanisms, such as appropriate equipment, might diminish their profits. This financial benefit to employers contrasted with the physical costs faced by Sara’s father, such as swollen hands and chronic back pain.

The groups decided not to consider their parents’ workplace problems for their self-selected projects because, in Tomás’s words, “There are a lot of people who don’t have papers [legal documentation of citizenship status] to work there. They [the employers] might think something is happening. That’s why we shouldn’t involve with that.” Nonetheless, ethical considerations shaped the groups’ activity at the problem-definition stage, when most groups sought to develop designs that aided historically vulnerable or disadvantaged populations, such as persons living below the poverty line and those with disabilities. Groups often evaluated their design solutions according to whether or not they would be accessible to populations that were being harmed, or at least not benefited, by their current contexts.

These ethical considerations not only helped them to define their target audience in the problem-definition stage, but also shaped their criteria in the evaluate-solutions stage. All groups stated that safety and accessibility for potentially vulnerable populations were more important than other evaluative criteria, such as the design’s potential to generate large amounts of revenue. They often cited past experiences with their family members’ ill health or injuries as evidence for why they valued these criteria above others. Sofia, for example, stated that one of the most important criteria for her group’s design was that “the headrest should be affordable to people who do not have a lot of money.” Her rationale for valuing this criterion was that her grandmother had diabetes but could not afford the diagnostic equipment or treatments recommended by her doctor. Hence, she reasoned that families with sick or disabled members were often already financially limited because they spent a large

portion of their income treating the illness or disability, and consequently she insisted that the device be financially affordable to poor families.

In addition to shaping their evaluative criteria, the adolescents' familial experiences with injuries also fostered an overall sense of empathy. For example, in the problem scoping stage, Group 7 initially considered improving existing portable ramps for wheelchair-bound persons with degenerative diseases to help them ascend multiplatform porches. One person described "cool" wheelchairs she had seen with wheels resembling cogwheels, similar to gears, that made it easier to climb up stairs. In response, Tomás stated that persons with degenerative muscular diseases "like my brother think they're going to fall. Their bones break so easy. Even falling on the grass would be scary. Even going on a bump is scary." To support this assertion, he described a time when his brother hit a bump while in his wheelchair, fell, and broke both of his thigh bones.

In this statement, Tomás evaluated a product, not from the perspective of an outsider observing a device that could perform "cool" external feats, but from the perspective of a physically fragile, wheelchair-bound person who was scared of falling. For that reason, he believed that the interconnected wheels would not be a satisfactory solution if it caused the person in the wheelchair to experience jarring. As in this example, we found that the participants' experiences with their relatives' injuries enabled them to consider solution elements from the vantage point of persons whose physical characteristics, psychology, and life experiences were different from their own. Such empathy is especially important to the work of engineers, many of whom are able-bodied, middle class, and possess other cultural and physical traits that are not shared by some clients who live under a different set of needs, constraints, and beliefs (Rasoal et al., 2012; Walther, Miller, & Kellam, 2012).

Transnationalism

All participants' families were transnational because their daily activities connected them with family members in other countries (Lam & Warriner, 2012; Vertovec, 2009). Most of the participants routinely exchanged photographs and messages with these relatives on social media sites. They also exchanged money and goods such as medicines. Seventeen of the participants had lived in Latin American countries or had stayed with relatives there for extended periods of time. Drawing from these transnational experiences, the participants developed context-based evaluative criteria for their engineering designs by recognizing that persons' needs, conditions, and conventions vary from context to context.

As an example, Carla helped her father lay roof shingles in both Mexico City and Parley (pseudonym for a rural town in the Western United States). Carla observed that in Mexico City, "The roofs are flatter than here [in Parley]. We have to have them inclined so that the snow falls off . . . but they don't have the need to account for snow." Moreover, in Mexico City, a few of her relatives' roofs were "kind of like shingles but they're made out of clay. If we had those here, the cold would crack them." Because of the population density in Mexico City, people "have to use all the space they can," so her cousin often slept on his flat roof. She explained that many people in Mexico City were unable to build patios in front of or behind their houses because "the streets are so close, they don't have a front yard and a back yard." Consequently, the roof served a function similar to that of a patio.

As illustrated in the above example, the participants' transnationalism gave them firsthand experience with considering sets of regional conditions, such as weather and local sociological factors, when evaluating designs. In this case, Carla evaluated a design element, clay, as satisfactory for roofs in Mexico City but unsuitable for Parley, where melting snow could seep

into the porous material, freeze, expand, and crack the roof tiles. Although she did not explain the scientific principles behind weathering, her father had taught her that weather conditions should be considered when deciding which roofing materials would be appropriate for a given region. She also evaluated a solution element, flat roofs, as being appropriate for certain areas but not others when she claimed that factors such as high population density and minimal snowfall made flat roofs better for Mexico City than for Parley.

Like Carla, Paula and Carissa drew from their internationally derived funds of knowledge to evaluate devices and systems according to region-specific criteria. They had both lived in Honduras and had routinely communicated with parents, grandparents, or other family members who still lived there. During group meetings, they compared and contrasted their experiences with water distribution systems in Parley and rural Honduras when they sought to bring safe drinking water to families in Honduras. They stated, on the basis of what their relatives told them, that government officials in Honduras often pocketed money designated for infrastructure repairs. Although Parley relied on a regional water distribution system, they did not want to take a similar approach to bringing potable water to people in Honduras. Although rivers were a primary water source in Parley, Paula did not want to rely on rivers in Honduras "because people dump their waste in them." Instead, she believed a water catchment and filtration system placed close to each house would be a more feasible design in rainy regions of Honduras.

Paula and Carissa's transnationalism formed the basis for several aspects of their design thinking. They initially brainstormed several possible approaches to helping people without consistent access to water – obtaining it from rivers or improving the overall infrastructure for water distribution – but they decided that longstanding local practices, such as political corruption and dumping waste into rivers, rendered these solutions less workable than individual rainwater catchment systems. This line of reasoning demonstrated one form of feasibility analysis. Because they had observed frequent rainfall in Honduras, they hypothesized that a roof-based water catchment system would be reasonable there, in contrast to Parley, where they said a water catchment system would not work because of relatively infrequent rainfall. They also used their transnational experiences as a basis for systems thinking by articulating that designs might work in the context of one political, social, and ecological system but not in another. In all, as demonstrated by these examples, the participants drew heavily from their transnational experiences to enact engineering design processes as they considered context-specific factors.

Household Management

All participants had engaged in maintenance and construction projects around their households and yards with the purpose of improving living conditions for their families and animals. These projects included fixing a variety of household items, leveling their yards, and building sheds, garages, stairs, and a fire pit. While describing a household project, Sofia mentioned how she improved a square enclosure in her yard. This enclosure was made of wire from a chicken coop, and it surrounded two doghouses in order to keep two small Chihuahuas from escaping the yard. When they left their doghouses to urinate outside, they became wet from snow and were exposed to cold winds. Sofia stated that their body temperatures dropped to unsafe levels and they frequently became ill. To solve this problem, Sofia brainstormed and wrote a list of solutions that would protect her dogs from snow and strong gusts of wind. These solutions used available materials around their yard because "it would be less money."

In the end, she placed a tarp around the chicken wire, reasoning that it would keep the snow from blowing in from the sides. She also found old wooden boards in her garage that she placed over the top of the wire enclosure to prevent snow from entering the doghouse area. Because the wire fence had previously “ended up flying off to the neighbor’s house,” Sofia added metal reinforcements to part of the fence and placed concrete bricks on the ends of the wooden planks to fasten them down in order to “make it [the enclosure] a little bit stable.” Although she noted that “over time I know wood gets rotten,” she evaluated her improved enclosure as being satisfactory because the fence did not fall down or fly away, and her dogs did not subsequently become excessively cold or ill. She also noted that her solution did not require her family to buy additional materials.

This example demonstrates several practices relevant to engineering. Sofia defined a problem and articulated several criteria that her solution must meet, such as that it must keep the dogs dry, it must be stable, and it must not cost additional money for materials or labor. She gathered information about material constraints when she spoke with her mother, who advised her regarding which materials her family would be willing to donate to the doghouse. She generated ideas in a list format and evaluated potential solutions according to her specified criteria. That is, she knew that wooden planks would rot, but in the end decided to use them because they did not cost any money. Her thinking indicated that she weighed competing criteria (long-lasting versus financially viable). Finally, she evaluated her solution using data from the outcomes of her project, such as whether the dogs became sick the following winter and whether the fence flew away.

Sofia applied the skills she had gained from household management to her group’s self-selected project, the shower chair headrest, as well. Sofia stated, “I mainly learned to sew from my grandma.” Later, Sofia applied this craft around her household as she sewed rips in the family couch, sewed aprons, and fixed tears in her siblings’ clothes. After her group had decided to use marine vinyl as the outer material for their shower chair headrest, Sofia used this skill to construct and test a model headrest pillow in order to determine whether it would repel water. She sewed the seams on the inside of the marine vinyl, stating,

I knew that it [the seam] was going to be air tight because I’ve made a lot of things. If the clothes were sewn like this [with the seam on the outside], they would break faster and you would notice that the thread would fall off.

To ensure that an inside seam would be better for the headrest than an outside seam, Sofia’s model pillow included three seams sewn on the inside of the pillow and one sewn on the outside. When her group pushed down on the pillow, air escaped from the outside seam but not from the three inside seams. The results from this test led the group to conclude that their final headrest pillow should be sewn with all inside seams to prevent shower water from entering the pillow. Sofia had also placed her model pillow under running water to ensure that the material repelled water and that water would not enter the inside seams. From these tests and Sofia’s insights, the group’s final description of their design specified that all seams for the headrest pillow should be sewn on the inside to prevent the thread from getting caught and tearing, as well as to more fully prevent water from reaching the inner foam.

In this case, we argue that Sofia’s household skill of sewing helped her group to recognize issues related to production and processing while they considered how a device’s production (for example, how it is sewn or constructed) affected its final overall effectiveness or ability to meet the stated criteria. We also assert that this skill was relevant to other codes related to

engineering design processes, in the sense that it enabled the group to construct and evaluate a physical model, which in turn informed what they communicated to the client in their final design. Finally, Sofia had learned how to evaluate solutions to problems by examining their outcomes, such as whether or not a seam ripped easily, and she applied this practice to her engineering project when she evaluated the physical model on the basis of whether water entered the seams.

Volunteerism

The National Academy of Engineering (2008) argued that teachers and other stakeholders should emphasize that “engineers make a world of difference” in order to encourage under-represented populations to enter engineering professions (p. 8). The prevalence of volunteerism throughout this dataset indicated that the participants actively sought to make a difference and contribute to their communities. Twenty-three of the 25 participants had volunteered locally by helping the elderly with household repairs, working at food banks and retirement centers, organizing blood drives, giving motivational “stay in school” speeches to Latina/o children, and participating in many other unpaid service-oriented activities. The following example illustrates how one participant obtained engineering-related funds of knowledge from volunteering and how she applied that knowledge to her group’s self-selected project.

Zoe volunteered weekly at a local animal shelter where she often restrained feral cats while a veterinary technician gave vaccination shots to them. In the process, the veterinary technician explained why she administered some shots intramuscularly and others intravenously in specific areas of the body. She further explained how one type of vaccination had to be administered in the cats’ leg muscles, because, in rare instances, it had been known to cause tumors, in which case the leg could be removed without killing the cat. In addition to learning about vaccine administration, Zoe also learned how to prevent the spread of infectious disease through using new needles for every cat and through washing her hands before she touched a different cat.

Zoe applied this knowledge to her group’s self-selected project, which entailed improving a commercially popular cat-nabber, or a device used to restrain feral cats. The group relied heavily on Zoe’s knowledge and her connections to the animal shelter as they defined the problem with the current cat-nabber. They argued that one problem with the current cat-nabber was that it had two meshes, which were difficult to spray with disinfectant. In their words, “Cats have diseases, and you have to clean it [the mesh] every single time.” To ensure that the cat-nabber was more easily washable, the group implemented a single-mesh design in which the mesh could be quickly sprayed on both sides, as opposed to the current double-mesh design in which one mesh had to be lifted in order to spray both sides of the second mesh.

By testing the current cat-nabber, Zoe and the vet technician also found that the fabric used for the mesh enabled the technician to give intravenous shots in a cat’s shoulder, but it did not enable her to give intramuscular shots in its legs because it was too tight for the cat to be maneuvered into the correct position. Zoe’s group remedied this flaw by selecting a more flexible, yet still snug, type of fabric that would enable veterinarians to give both types of shots. As suggested by this example, by volunteering at an animal shelter, Zoe gained scientific knowledge relevant to her group’s project. She learned how infectious diseases are spread, and she knew why some vaccines had to be administered in different areas of the body. This knowledge, in turn, informed her group’s thinking as they defined criteria for a successful design and selected solution elements based on those criteria.

Community Organizations

Twenty participants were members of community-based organizations, such as churches and the Boy Scouts of America, and they occasionally acquired engineering-related funds of knowledge through participating in activities sponsored by these organizations. As an example, Emiliano participated in a sewing club, and he applied what he learned from this club to his group's project, which was to improve an existing water-resistant shoe for running and playing in the snow. Samuel, another member in this group, suggested that the upper part of the shoe should be made out of several layers of fabric, such as polytetrafluoroethylene to repel water and wool to provide warmth. When justifying these suggestions, Samuel initially mentioned only the properties that he wanted for the end product, but Emiliano questioned how they would construct this type of multilayer shoe. He stated that they should use the thinnest needle and thread possible to sew the layers together because "if it (the needle) is too big it leaves holes and it doesn't look good." He also wondered whether holes would prevent the shoe from being waterproof.

At the same time, Emiliano noted that thinner threads were often easier to break, especially in thicker materials, and he wondered which type of thread should be used to "[seam] two different types of fabric together" without producing unnecessarily large holes in either material. This conversation led the group to question whether they should sew the materials together or paste them together with industrial glue. In this example, Emiliano evaluated the feasibility of Samuel's selection of materials. Unlike his group members, he did not evaluate this solution element in terms of whether each material individually exhibited desirable properties, but in terms of whether and how these materials could be realistically combined. He also considered how factors related to the production process (e.g., using thinner or thicker thread, using thread versus glue) would influence whether the final shoe met the group's criterion of being waterproof. Throughout this reasoning process, Emiliano applied the lessons he learned from the sewing club to evaluate whether or not a particular solution element would be possible to produce.

Sports

Eleven of the participants played organized sports, and four of them were avid soccer fans, who displayed the insignia of their favorite teams on their backpacks or other apparel. They joined online forums to discuss soccer-related trends, such as the shoes that their favorite players wore. Samuel and Patricio frequently cited their sports-related funds of knowledge as they worked with Emilio to improve an existing shoe for running and playing in the snow. In his interviews and during group meetings, Patricio, a longtime soccer player, compared and contrasted the surfaces of indoor and outdoor soccer fields in Honduras and Parley. He argued that different shoe soles gained better traction on different surfaces:

For cleats, they have the big ones [studs] in the grass so they can get good grip, but . . . for *futsal*, I mean for indoor soccer, they came up with the small ones. They're the same but they have a lot more [studs] and they're smaller.

Here and elsewhere, Patricio explained that players needed longer studs to "get more traction in the grass," but they needed shorter studs to play indoors on firmer surfaces.

Patricio noted that when he wore his outdoor soccer cleats to run in parking lots, their traction was poor because "they don't sink in, so they're just on the studs." Samuel agreed: "Walking on concrete [in soccer cleats] can be uncomfortable because it's like you have so many little points making contact with the concrete. So you have less traction because less

surface area is touching the ground.” Because Patricio and Samuel thought the users of their proposed shoe would walk over hard ice, and large studs would not “sink in,” they designed a shoe with deep grooves and “more surface area touching the ground.”

In this example, the participants drew from sports-related funds of knowledge to define the problem. Drawing on their experiences with soccer cleats, they knew that any given sole design would perform differently under different physical conditions. They therefore identified the physical conditions under which their shoe would be used prior to planning their sole design. They used their experiences with cleats to speculate on physics, such as their hypothesis that shoes with little surface area touching the ground would exhibit less traction on hard surfaces, and they applied these principles to the design of their own shoe. In sum, they attempted to use scientific knowledge to understand and define the problem, a practice that is common to engineering.

Popular Culture and Digital Technologies

The participants engaged in other recreational activities that provided them with engineering-related funds of knowledge. Seven participants watched and read popular television shows and books that gave them insight into aspects of engineering practice, such as Steve Wozniak's autobiography (Wozniak & Smith, 2007), and *Design Squad*, a television show in which teams of teenagers solve problems through engineering. Several of the participants and their friends also played popular digital games relevant to engineering. These games included apps in which they built bridges, carts, or circuits and redesigned them according to their performance. Games also included fashion apps in which they collected information from a variety of sources – such as observations of clothes, feedback from clients, and sales data – and used them to evaluate and remake fashion designs.

Four participants played games in which they built civilizations and evaluated their decisions according to the game's outcomes. While playing one of these games, Mateo considered spatial factors when planning his city:

The industrial parts get really polluted, so you want [them] away from the city when you have the shops. Because if you put an industrial part next to a house, the people there are going to start getting sick.

Consequently, he placed industrial areas on the city's border in the opposite direction of where the wind tended to blow. Mateo was also thoughtful about how he increased and responded to different “demands,” a term used in the game to indicate what the city inhabitants needed. For example, when Mateo installed more homes, employment demands increased, so he installed businesses and colleges. Because people needed transportation to school and to work, he installed a bus terminal. He described how these installations in turn affected other aspects of the city. He noted how installing the bus terminal led to an increased number of out-of-city visitors, who in turn increased commercial revenue. He noted how the installation of the college increased population, which in turn led to the need for more hospitals and fire stations to ensure health and safety.

As indicated by this example, video games at times provided the participants with opportunities to practice systems thinking. In this case, Mateo used a chain of cause-and-effect reasoning, within the context of a larger system, to make projections about which solution elements would have desired effects. He then evaluated his solutions using large-scale trends in economic data and health data. Mateo iteratively used feedback from different types of

data to inform his design decisions while considering multiple system outcomes (for example, amount of revenue, level of health, size of city). Such thinking is highly relevant to engineering because engineers predict how changes in system variables will influence outcomes, including environmental and economic ones (Frank & Waks, 2001).

Implications

Engineering cultures are often alienating to Latinas/os and to other minorities (e.g., Foor, Walden, & Trytten, 2007; Stevens, O'Connor, & Garrison, 2005), but this study's findings highlight "points of cultural intersection" (Grimberg & Gummer, 2013, p. 12), or ways engineering practices can connect with Latina/o adolescents' everyday practices. This study's findings suggest that the participants held funds of knowledge that were relevant to engineering design processes, bodies of knowledge, skills, and habits of mind. While in their homes, communities, and recreational settings, the participants addressed complex real-world problems. They used tools, systems thinking, knowledge of production and processing, or scientific knowledge to define, evaluate, and address problems. Furthermore, when asked to identify and solve a problem through engineering, they applied their funds of knowledge toward the development of their solutions.

By connecting Latina/o adolescents' funds of knowledge to formal engineering practices, educators can create third spaces in which their students' funds of knowledge are treated as assets throughout the engineering design process. This type of culturally responsive instruction can be used by science teachers who seek to implement the engineering design component of the *Next Generation Science Standards* (NGSS Lead States, 2013), as well as by technology and engineering teachers whose national standards likewise address engineering design (International Technology Educators Association, 2007). The following hypothetical scenario illustrates what culturally responsive engineering instruction might look like. This scenario draws from the above example in which Sofia improved an enclosure for her Chihuahuas. We selected this example because it represented a common problem across our dataset: Ten families in this study had built or modified enclosures to keep their animals warm during the winter, and 22 of the 25 participants owned animals that lived outdoors.

In order to provide culturally responsive instruction, a science or engineering educator first seeks to know her students and their communities. At the beginning of the year, she administers a survey in class to ascertain their engineering-related funds of knowledge (Sias, Wilson-Lopez, & Mejia, in press). She actively seeks to position her students as experts throughout the academic year by asking them to share their engineering-related expertise and experiences that she discovered through the surveys. The teacher and students collaborate together to select the problems that they want to solve through engineering. In this particular class, because many students in the region own animals that live outdoors and because they are interested in learning how to keep their own animals warm during the winter, they decide to help their classmate Sofia redesign an enclosure for her Chihuahuas.

Sofia describes the problem with her existing enclosure, and she shows photographs she had taken of her yard. When she states that she needs to use available materials, the teacher introduces the concept of constraints. As Sofia and her classmates identify the outcomes that they hope to gain after constructing a dry and covered enclosure, the teacher introduces them to the concept of measurable and observable criteria. The teacher then leads them through a matrix or list in which they prioritize the criteria and constraints needed for a

successful solution. After Sofia states that she wants to use wood because it is readily available, even though it weathers quickly under winter conditions, the teacher introduces the class to the concept of tradeoffs and ask students to identify other potential tradeoffs involved in the decision-making process.

Later, working in small groups, students produce visual and physical models of a dog-house enclosure. Before they test the models, they learn relevant scientific and mathematical concepts, such as concepts related to structural stability. They devise a method for measuring stability, and they test and measure the stability of their physical models using this method. The teacher then introduces mathematical formulae that measure stability, and the class compares their method of measurement to the formal method. They redesign and retest physical models based on the scientific and mathematical principles they learned. Last, the small groups present their final physical models, along with written and visual descriptions of their proposed designs, to Sofia's family for their consideration. The family reports back on which design they implemented, why they selected that design, and what its outcome was.

This hypothetical scenario demonstrates how engineering educators can meet many of the criteria for culturally responsive instruction grounded in third-space theory. The instruction described in this scenario blurs the physical boundaries between home and school by grounding curricula in home-based spaces. It challenges traditional teacher-student roles by positioning Sofia as the expert regarding the problem, thereby upending typical hierarchy in the classroom. Finally, it meets the pedagogical requirements of third-space instruction by including "relevance as starting point" (Barton & Tan, 2009, p. 68) rather than formal concepts, such as weighing tradeoffs and structural stability as starting points.

The findings from this study can serve as a case study for secondary education teachers who seek to connect funds of knowledge to engineering. The hypothetical scenario illustrates the potential of using participants' funds of knowledge as springboards for culturally responsive instruction. To demonstrate that engineering is applicable to everyday life, teachers can create recruiting and instructional materials with problems drawn from different branches of engineering to appeal to adolescents with varying forms of funds of knowledge.

Like Felicia, most of the participants in the study had engaged in large-scale food preparation at their workplaces or while making food for large birthday parties such as *quinceañeras*. Teachers could draw from these experiences to introduce concepts related to industrial engineering. Because many adolescents in rural areas work with animals on farms, teachers in these areas could introduce problems dealing with biological and agricultural engineering. Teachers who work with transnational adolescents could solicit their students' observations to introduce factors relevant to civil engineering. In sum, STEM teachers can draw from the different funds of knowledge that Latina/o adolescents possess to inform their culturally responsive instruction and overall pedagogical approach.

Future research can test whether culturally responsive engineering instruction improves Latina/o adolescents' outcomes in engineering. This study provides an important first step in moving toward this type of instruction by showing how Latina/o adolescents' skills, practices, and daily experiences aligned with engineering practices. Our study suggests that adolescents do not need to abandon their familial, recreational, or community practices in order to become an engineer. Future research can also determine whether Latina/o adolescents in different geographic regions possess additional or different categories of funds of knowledge than those outlined in this study. These funds of knowledge can likewise serve as the basis for culturally responsive instruction.

Conclusion

This study does not imply that culturally responsive engineering instruction is applicable only to Latina/o students. On the contrary, previous research has suggested that African American adolescents (Barton & Tan, 2009), working class rural White children (Johnson, Baker, & Breuer, 2007), and Native American children (Civil, 2002) possess funds of knowledge relevant to mathematics and science. The National Research Council (2012) stated that STEM education should relate to the interests and life experiences of all students. Accordingly, engineering teachers should actively solicit the relevant interests and life experiences of all of their students, Latina/o and otherwise, and integrate them with formal engineering design processes. In this study, we focused specifically on Latina/o adolescents because Latinas/os are not entering STEM fields at the same rate as their White counterparts. One of our participants, Sara, articulated the concern of this paper well:

I don't feel like engineering has been a big thing that people know about, especially lots of Hispanics. We don't really know because we aren't really brought into engineering.

Although Sara did not feel as though she and her Latina/o peers were encouraged to become engineers, they still exhibited knowledge and skills that were conducive to engineering thinking and practice. They drew from engineering-related funds of knowledge in order to work on self-selected, community-based projects and in order to solve other problems in their everyday lives. To reverse national trends of Latina/o underrepresentation in engineering, educators can draw from these funds of knowledge to help adolescents address problems that are of interest to them while simultaneously introducing formal engineering-related practices and bodies of knowledge. Further research can determine whether a third space of learning and knowing can be used to bring Latina/o students into engineering by making explicit connections between this discipline and their everyday lives.

Appendix A Protocol for Introductory Interviews Regarding Funds of Knowledge

Self

Tell me about yourself.

If somebody asked you to write a story about your life, what would you put in it?

What are your interests?

What are your talents?

What are you passionate about?

What do you like doing after school?

What do you do during the summers?

Is there anything else important for me to know about you?

Family and Household

Tell me about your family.

What do your parents/guardians/older siblings do for a living?

Have you ever helped them with their work? Please describe a time when you helped them.

What does your family do when they're not working?

Have you ever helped them with a project? Please describe a time when you helped them.

Please describe where you live.

Please describe your yard (if applicable).

Have you ever helped your family improve your household or yard? Please describe a time when you helped them.

Do you have chores that you are responsible for? Please describe them.

Are there jobs around your home that have been challenging to do? Please describe them.

Do you own any animals? Please describe them.

Is there anything else important for me to know about your family or your home?

Friends

Tell me about your friends.

What do you like to do with your friends?

How do you and your friends communicate with each other through technology?

Do your friends like solving problems or building things? Please describe a time when they (solved a problem).

Is there anything else that is important for me to know about your friends?

Workplace

Do you have a job, or have you ever held a job? Please tell me about it.

Please describe a typical day at your work.

Are there changes that could be made or tools that could be developed that would make your work go better?

What ideas do you have for making your work go better? Have you tried to implement any of those ideas?

Is there anything else important for me to know about your work?

School

Tell me about your school.

What are you involved in at school?

Think about the ways people work and play at your school. Are there changes that could be made or tools that could be developed that would make the activities go better?

What ideas do you have to make those activities go better? Have you tried to implement any of those ideas?

Is there anything else that is important for me to know about your school?

Neighborhood

Tell me a little about your neighborhood.

Think about the ways people work and play in your neighborhood. Are there changes that could be made or tools that could be developed that would make living in your neighborhood better?

What ideas do you have to make your neighborhood better? Have you tried to implement any of those ideas?

Is there anything else that is important for me to know about your neighborhood?

Community Service

Have you ever provided community service through church, an after-school club, or some other organization? Please tell me about it.

What kinds of problems did you try to solve through community service?

How did you help to solve those problems?

Is there anything else that is important for me to know about your experiences with community service?

Follow-Up Question Used for Previous Questions

You said (XXX, e.g., you liked to play Age of Empires). Can you tell me more about that?

Will you describe (XXX, e.g., how you decide what kind of materials to use when building walls while playing Age of Empires)?

Appendix B Protocol for Ongoing Interviews Regarding Funds of Knowledge

Did you do any work on the engineering project any time between now and the last group meeting? Tell me more about that.

What sources have been helpful to you this month as you work on your project? Why were those sources helpful?

Here is [show a student-generated product, such as a sketch or a survey]. Can you tell me more about that? What kinds of things were you considering as you made that? Have you had experience with making things like this before? Please describe that experience.

I noticed that you [interviewed a neighbor, referred to a hydraulic system at your workplace] during your last group meeting. Will you tell me more about that? What did you learn from that experience? Do you think that experience applies to the project you are working on? How?

Before, [while you played the apple cart game], you explained to me that [you shaped your cart in a certain way to keep the apples from bouncing out]. Do you think that concept applies to [the shower chair] at all? Will you explain how?

In what ways does [this aspect of the problem] remind you of any similar experience you have had? What parts are similar? How are they different?

Can you think of any other ways that this problem reminds you of something you know about from personal experience?

Appendix C

Protocol for Group Meetings

Beginning of Meeting

Would somebody please summarize what we did at our last group meeting?

What are your goals for this group meeting? What do you hope to accomplish?

During Meeting (if needed)

[Name of participant] suggested [XX]. What do you think about that idea?

What should the next steps for this project be?

Could you summarize the problem in your own words?

How will you know if your solution is successful?

What questions do you still have or what information do you still need?

How could you find more information about this project?

How could you test your idea?

Who should you share your ideas with? Who could evaluate it? Who could benefit from it?

How would you summarize feedback from the client? How might you need to modify the device based on feedback and your own testing?

End of Meeting

Let's return to the engineering design cycle pasted in your Engineer's Notebooks. Where do you think you are in the process? Why do you think that?

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