"As a Squash Plant Grows": Social Textures of Sparse Internet Connectivity in Rural and Tribal Communities

MARISA ELENA DUARTE, Arizona State University
MORGAN VIGIL-HAYES, Northern Arizona University
ELLEN ZEGURA, Georgia Institute of Technology
ELIZABETH BELDING, UC Santa Barbara
IVONE MASARA, Arizona State University
JENNIFER CASE NEVAREZ, Community Learning Network

Researching and designing Internet infrastructure solutions in rural and tribal contexts requires reciprocal relationships between researchers and community partners. Methodologies must be meaningful amid local social textures of life. Achieving transdisciplinarity while relating research impacts to partner communities takes care work, particularly where technical capacity is scarce. The Full Circle Framework is an action research full stack development methodology that foregrounds reciprocity among researchers, communities, and sovereign Native nations as the axis for research purpose and progress. Applying the framework to deploy television white space infrastructure in sovereign Native nations in northern New Mexico reveals challenges for rural computing, including the need to design projects according to the pace of rural and tribal government workflows, cultivate care as a resource for overworked researchers and community partners, and co-create a demand for accurate government data around Internet infrastructures in Indian Country and through rural counties.

CCS Concepts: • **Networks** → **Wireless access points, base stations and infrastructure**; • **Human-centered computing** → **Human computer interaction (HCI)**; **Ethnographic studies**;

Additional Key Words and Phrases: Native American, rural computing, spectrum, community-based participatory research

ACM Reference format:
Marisa Elena Duarte, Morgan Vigil-Hayes, Ellen Zegura, Elizabeth Belding, Ivone Masara, and Jennifer Case Nevarez. 2021. "As a Squash Plant Grows": Social Textures of Sparse Internet Connectivity in Rural and Tribal Communities. *ACM Trans. Comput.-Hum. Interact.* 28, 3, Article 16 (June 2021), 32 pages.
https://doi.org/10.1145/3453862

This work was funded by NSF CNS-1831698.
Authors' addresses: M. E. Duarte and I. Masara, School of Social Transformation, Arizona State University, PO Box 874308, Tempe, AZ 85287-4308; emails: {marisa.duarte, imasara}@asu.edu; M. Vigil-Hayes, School of Informatics, Computing, and Cyber Systems, Northern Arizona University, PO Box 5693, Flagstaff, AZ 86011; email: morgan.vigil-hayes@nau.edu; E. Zegura, School of Computer Science, Georgia Institute of Technology, 266 Ferst Drive, Atlanta, GA 30332-0765; email: ewz@cc.gatech.edu; E. Belding, University of California, Santa Barbara, 2104 Harold Frank Hall, Santa Barbara, California, 93106-5110; email: ebelding@ucsb.edu; J. C. Nevarez, Community Learning Network, Po Box 33423, Santa Fe, NM 87594; email: casejcc@yahoo.com.

1073-0516/2021/06-ART16
https://doi.org/10.1145/3453862

1 INTRODUCTION

This article is about an experience of working with the board members and technology experts of a joint cooperative Internet network backbone in northern New Mexico to extend last-mile Internet connectivity and access to the member communities, including rural and semi-urban municipalities and counties and four sovereign Native nations, through deployment of **television white space (TVWS)** wireless technologies. Our core project team is interdisciplinary and consists of **human–computer interaction (HCI)** researchers, an information scientist, graduate student computing and geographical information systems researchers, and community representatives, including board members of the network cooperative and a grassroots community learning and technology advocate. Our team has significant prior experience working in Indian Country. [21, 84–87]

The COVID-19 pandemic greatly affected our initial project plan. Native Americans are severely impacted, representing over 50% of New Mexico's COVID-19 deaths as of May 2020. Our project partners had to rapidly pivot their **information technology (IT)** capacities to handle unprecedented surges in residential Internet traffic, and emergency communications solutions along tribal borders and amongst hospitals and mobile clinics. The relational emphasis of the Full-Circle Framework, which we detail in Section 4, empowered us to adjust, redirect, and provide support in unexpected ways.

As we detail our experiences, we contribute the following to the HCI community and the subfield of rural computing:

- We introduce the Full-Circle Framework, a feminist participatory approach for discerning digital inequities through system design in communities with relatively autonomous cultural values and governance practices, including tribal sovereignty.
- We highlight how the Full-Circle Framework enables us to engage with rurality in an inclusive and equitable manner, in spite of the pressures of urban university lab-centric technical design and digital divide interventions.
- We reflect on how we leveraged the framework to enable our team to respond with care amid the COVID-19 pandemic.
- We reveal points of advocacy for sustaining innovation in rural computing, including public access to accurate data about spectrum in rural regions, simplified and accessible licensing processes, and funding and project timelines that account for rural pace of life.

Ultimately, we find that rural broadband infrastructure "scales as a squash plant grows."[1] Squash plants sprawl with vines that adhere to existing support structures; their fruits take time to mature; it is difficult to predict the direction of growth; and they are "heavy feeders," requiring frequent replenishing of soil nutrients. This analogy for rural and tribal Internet infrastructure innovation allows us to discern solutions to digital inequalities as organic efforts that require persistent cultivation to bear fruit.

We begin with an overview of related work in Section 2. In Section 3, we contextualize rurality in northern New Mexico and with regard to Internet infrastructure in Indian Country.[2] In Section 4, we describe the Full Circle Framework as a participatory approach to addressing digital inequities

[1]An apt observation about rural broadband growth made by our community research partner, Jennifer Case Nevarez, meaning that the growth is organic and somewhat arbitrary.

[2]"Indian Country is a legal term that refers to the federally-recognized tribes, state-recognized tribes, pueblos, rancherias, bands, and Alaska Native villages and corporations within the political boundaries of the United States. Used colloquially and not in a legal sense whatsoever, Indian Country also refers to Native peoples habits and norms in this somewhat parallel society. As a legal term, the phrase Indian Country has come to have meaning out of the basis of over a century of treaty-making and recognition processes between Native peoples and U.S. federal authorities. It inherently refers to an intertribal state of being for Native peoples in the United States [21]."

in rural and sovereign tribal contexts. In Section 5, we demonstrate how we employ the framework. We end with a discussion of insights and challenges in Section 6 and conclude in Section 7.

2 RELATED WORK

Our work is informed by three major bodies of work: digital divide and rural computing, frameworks for working with communities, and concepts of decolonizing technologies.

2.1 Digital Divide and Rural Computing

A significant body of work examines and characterizes digital inequalities. A 1995 National Telecommunications and Information Administration conceptualizes the "digital divide" as a social binary between "haves" and "have-nots" [13]. Researchers now evaluate access with regard to technical barriers that shape the quality of user productivity (e.g., fixed vs. mobile service and public vs. private access). Internet use researchers have since identified a "second-level divide," including a "skills-divide," wherein lack of skill exacerbates lack of technical access. Moreover, a "third-level divide" characterizes situations where Internet is accessible and skills are present, but persistent digital inequities limit social, educational, and economic benefits of Internet access [71, 77, 82, 89]. Related work demonstrates how digital divides reinforce existing social inequities [40, 79, 83, 92].

Our work is also related to rural computing, which examines challenges and opportunities associated with places where digital divides are persistent. This work appears in multiple subdisciplines of computing, from HCI to networking, though tends to be understudied [95]. The rural represents an environment distinct from the urban, and yields particular beliefs, desires, intentions, experiences, and practices surrounding digital technology [37, 38]. Indeed, Mattern suggests that rurality provides an epistemic counterpoint to technicized urban environments, such that rural dwellers inhabit spaces differently, an insight bolstered by Burrington's cultural geographic survey of urban markup language in New York City and Say Chan's ethnography of nationalist networking efforts in rural and Indigenous Peru [16, 51, 70]. Our field site is culturally and geographically diverse, with colonial Spanish, Mexican, Puebloan, Navajo, and Apache histories predating Anglo-American establishment of the United States. Denizens describe themselves as multicultural, although political and historical schisms and gentrification processes distinguish the social agendas of the Native American peoples, Hispanic people, and the Anglo population of the state. Race, wealth and capital, religion, beliefs about development, political praxis, and historical treaties and land claims shape the milieu. Rural residents often describe their distance from the centers of political and economic power (Albuquerque, Las Cruces, Santa Fe, and Rio Rancho) as geographic and relational. Infrastructures, funding, and services designed for city dwellers—including high speed Internet infrastructure—will not reach the state's rural and reservation populations. History demonstrates that even if Internet infrastructure does make it to rural and tribal areas, it may not be sustained due to distinct economic agendas, challenges of remote mountainous or desert terrain, or lack of skilled personnel.

Thus, work that examines computer networks in rural tribal context is particularly relevant. Several authors have examined Internet uses and challenges in the **Tribal Digital Village (TDV)** network, a wireless **Internet service provider (ISP)** operated by 24 Native American tribes in San Diego County with the purpose of providing Internet access to underserved tribal communities [21, 69, 84, 85]. While Sandvig claims they are pressured to demonstrate that the Internet is used for education, economic development, and cultural preservation, rural tribal users on the TDV network use Internet the "way we would expect them to"; many users self-reported using the Internet for the same applications as non-rural, non-tribal users, such as e-mail, social media, and entertainment [69]. However, deeper examinations revealed critical differences in how the technology is used and maintained. In an extensive interview-based study of the TDV network, Duarte noted that while the applications used by tribal users were similar to those of non-tribal users, the intentions were connective and decolonial in nature [21]. For instance, geographically distant cousins would use Xbox Live to connect over shared experiences and tribal councilmen digitized and archived council meetings. These uses demonstrated how decolonizing Internet infrastructure could be, as it was being used by tribal peoples to connect to each other–a stark contrast to the Settler-Colonial policies that had forcibly disconnected them from each other in an effort to seize land, water, and natural resources from tribes [21].

Related work also examines how network usage in rural communities differs from urban usage patterns. In a study of social media practices by rural and urban MySpace users, Gilbert found that rural users were more likely to have stronger privacy preferences, to have strong and weak ties to other users who lived nearby, fewer online social connections, and were more likely to be female [32]. Johnson et al. examined the locality of content interest for Facebook users in rural Zambia and found that there was a strong preference for engaging with media generated by users from the same village [41]. In a study by Vigil et al., researchers collected and characterized anonymized network packet traces of rural tribal communities, revealing that tribal TDV users were extensively leveraging social media platforms to connect to other users on the same reservation or on reservations in the same region [84, 85].

In this article, we define rurality as a sociogeographical state of being characterized by distance from urban power and high relational dependence on one's "near neighbors" for the co-development of new resources. For this definition, we leverage the network theory concept of multidimensional networks to conceptualize the complex cultural interface among people who participate as actors across racial, familial, political, tribal, and geographical networks [4]. "Near neighbors" affiliate across multiple networks and establish strong links through long term collaboration. In our definition, "state of being" coheres with prior work by researchers who frame rural HCI with regard for rich sociocultural aspects of life [38]. Our definition is also based on our experiences working with Native nation technologists to measure, characterize, design, and deploy Internet connectivity solutions. We thus develop the Full-Circle Framework to account for the likelihood of these practices in our partner communities.

2.2 Frameworks for Working with Communities

Researchers working closely with underserved communities in both the global north and the global south have developed frameworks for thinking about and conducting collaborative work. We draw substantially on participatory action research and methods in the Latin American tradition, which advocate a cyclic process of diagnosis, action planning, action, evaluation, and specifying learning, grounded in principles such as reflective critique, collaborative resources, and plural structure [66, 78]. Communities and their knowledge are central, and the process builds capacity as a key goal of the research cycle.

Asset-based community development (ABCD) shares the commitment to close work with communities, but rhetorically and practically shifts away from a deficit or problem-based starting point, as reflected in terms like "diagnosis," toward advocacy for revealing and leveraging community assets [50]. ABCD's origins are in economic development work in urban America, and build on international development work that preceded it [46]. While not originally embodied in a process diagram—indeed, the original authors apparently resisted such a prescription—the elements of ABCD include storytelling, organization of a core group, mapping assets, building relationships among local assets, convening inclusive groups, and articulating resources outside the community toward locally-defined development [50].

With regard to global south efforts, the **Information and Communication Technology and Development (ICTD)** interdisciplinary research community has grappled with researcher positioning, relationships, and project sustainability for interventionist approaches, which has a checkered history and includes many project failures [20]. Consistent with ABCD tenants, scholars have argued that technology interventions can amplify local capacities, but will not produce social change outside of an understanding of culture and human behavior [79].

We thus also ground our work in a feminist ethics of care, which Gilligan (1982) asserts as a relational collective approach to social justice. Relationality is a compassionate response to heteropatriarchical individualism, subjugation of emotions, and negation of the knowledge of marginalized social groups. Importantly, HCI researchers guided by a feminist ethics of care consider the powerful nature of relationships between those involved in the generation, perception, and resolution of a research problem, and treat care as a resource toward system sustainability amid uncertainty [44, 54]. Through methods like action research, participatory design, community-based design, and self-reflexive ethnography, the researcher cultivates relationships, supports equitable participation and pluralistic solutions, and empowers project partners to care for those whom they serve: dependents, friends, community members, and loved ones. These values guide feminist CSCW and HCI researchers toward (i) appropriate design for participant communities, (ii) alternative design directions, and (iii) ethical and pragmatic trade-offs that community-based decision processes entail.

2.3 Decolonizing Technology

Lastly, this work is informed by investigations of infrastructures turned toward the divestment of colonial power. Contributions made by researchers in critical software studies and critical surveillance studies unmask the asymmetric power relations embedded in the design of algorithmic discrimination [1, 15, 61]. Srinivasan shows how subaltern groups around the world adapt infrastructures toward local justice in spite of systemic and structural oppression [75]. Duarte applies Quijano's coloniality of power to frame how Indigenous peoples decolonize technologies to counteract the theft and destruction of landscapes, and subjugation of Indigenous peoples, governments, and philosophies [21, 65]. Designers like Anishinaabe game designer Elizabeth LaPensee create systems to inspire decolonization. US oil industry representatives were notably threatened by LaPensee's free mobile game app Thunderbird Strike, in which players destroy an oil pipeline and revive animals with thunderbolts [22]. Deschine-Parkhurst shows how Indigenous social movements like Save Oak Flat employ social media toward what Vizenor identifies as Indigenous survivance: persistance in spite of colonial exigencies [63, 88].

Similar to these works, our investigation combines design with a relational and macrohistorical understanding of pernicious social inequities shaped by colonialism. Furthermore, because our work is guided by a feminist ethics of care, we do not adhere to post-apocalyptic visions of a datafied world order, but rather, find decoloniality to be an inspiring location from whence to imagine and co-create socially just futures for underserved peoples. Our work is distinctive for its consideration of multiple modes of marginalization: we examine rural computing as not just an economic and geographic phenomena, but also a cultural, racial, and Indigenous social and political phenomena. Our mixed methods approach frees us to understand computing needs and challenges from a technical infrastructure perspective and a people-centered perspective, wherein we account for the "actors that must be brought into alignment in order for [infrastructural] work to be accomplished" [49].

3 BACKGROUND

In 2017, Internet Society organizers invited two computer scientists on our team to present at the Indigenous Connectivity Summit in Santa Fe. We spoke about our prior work extending Internet connectivity in support of tribal network sovereignty, including how we identified TVWS wireless technology as a promising solution for areas with low population density and physically distant from robust fiber-optic infrastructure. After the talk, we were approached by representatives from **Regional Economic Development Initiative Network (REDINet)**, a middle-mile fiber network in northern New Mexico formed out of a joint powers agreement between four sovereign Native nations—Ohkay Owingeh Pueblo, Santa Clara Pueblo, Tesuque Pueblo, and the Pueblo of Pojoaque—and Rio Arriba County. They were interested in working with our team to deploy TVWS as a last-mile Internet solution to residents living in the canyon and forested parts of the Pueblos as well as near ancestral sites with regulations against trenching and aerial cables. Our team worked with the general manager of REDInet as well as Jennifer Case Nevarez, an educator through New Mexico Tech Works, a STEM spin-off of the local non-profit Community Learning Network, to plan the TVWS deployment and community digital skills training through the PuebloConnect project.

The REDINet service area is a short drive from Santa Fe, New Mexico, where colonial histories; mountainous high desert and canyon terrain; limited water and power infrastructure, roads, and housing; and distinctly Indigenous values distance the region from the wealth and commercial development of the city. Low population densities, few commercial businesses, and limited employment opportunities characterize the region. Two social and historical conditions distinguish REDINet from other community-based network infrastructures: (1) the distinctive nature of rurality, multiculturalism, and tribal sovereignty in northern New Mexico; and (2) challenges shaping Internet access and infrastructural build-out in Indian Country. In this section, we characterize these conditions.

3.1 Rurality in Northern New Mexico

With a population of 2.09 million, New Mexico is the fifth least densely populated state in the US. Most residents live in counties and small towns outside of the three major cities of Las Cruces (pop. 99,665), Albuquerque (pop. 558,545), and Santa Fe (pop. 83,776). The state's population averages about 17 people per square mile. Out of 121,298 square miles, 17.4% is managed by the **U.S. Bureau of Land Management (BLM)** and another 10% belongs to one of 23 sovereign tribes. The majority of BLM land is concentrated along the southern border, against the northern Mexican state of Chihuahua, whereas the majority of sovereign tribal land is concentrated in northwest New Mexico. Commerce and development occur alongside the east-west interstate highways I-10 in the south and I-40 in the north, which are connected by the north-south I-25 route. The three major cities are located at the intersections of these highways and also in proximity to, respectively, US military operations and national labs: White Sands Missile Range in the south, Sandia National Labs in the center, and Los Alamos National Labs in the north.

The sites for planned TVWS deployment are located along the middle and last mile service regions of the REDINet backbone. This includes the four Pueblos as well as rural regions in and around Rio Arriba County and the small town of Española, New Mexico. This also includes acequia collectives: historical communal agricultural regions shaped by cooperative water usage among colonial Hispanic families. Recently, with a pun on the local low-rider car culture, Española made headlines as having the third slowest Internet speed in the country [48]. These areas are governed by jurisdictional differences—tribal sovereignty and self-governing acequia collectives—that require additional layers of political representation, decision-making, negotiation and regulation *vis-à-vis* the state government. Figure 1 provides a visual perspective on the northern New Mexico landscape.

3.2 Internet in Indian Country

A 2016 report by the **Government Accounting Office (GAO)** noted that rural tribal communities were less likely to sustain Internet infrastructure due to a lack of interagency coordination

Fig. 1. View of the landscape from a water tower at Santa Clara Pueblo in May 2019. The drone in the photo was used for network data collection.

between the US Department of Agriculture Rural Utility Services grant programs and the **Federal Communication's Commission's (FCC)** Universal Services Fund programs [34]. This lack of coordination compounds shortages of skilled personnel in these locations, the high costs of trenching and stringing aerial cable through rugged terrain, and limited ability of users to pay higher than average costs of data plans. Telecom investors are thus often unwilling or unable to support or sustain rural infrastructure build-outs. Individuals working on Internet connectivity in rural northern New Mexico describe how federal funds and private investments privilege the commercial development and tax base of first-mile and middle-mile urban and semi-urban geographies: downtown Santa Fe and associated business corridors.

To complicate matters, a subsequent 2018 GAO report found that the FCC relies on erroneous ISP datasets for evidence of Internet access and coverage on tribal lands [35]. The erroneous FCC dataset overestimates actual rates of access, coverage, and connectivity, which makes it difficult for ISPs to develop realistic business plans and grant and loan applications. A recent op-ed compares the FCC reliance on spectrum misinformation to the formation of the 1887 Dawes Act, which promulgated misinformation about tribal sovereignty to ultimately divest Native Americans of their own lands [8]. The GAO findings reflect statistical reports indicating that Native Americans in urban locations tend to have more Internet access than their rural counterparts [64, 76]. These findings also confirm research that characterizes how and why tribal ISPs get their start, namely, to fill a gap in service that is related to rural or remote location, challenges in the terrain, sovereign jurisdictions, competition with regional telecoms for government grants and loans, and exclusion from urban economic development and technology capacity-building programs [21].

What is not indicated in government reports is the overwhelming social demand for reliable Internet access in rural Indian Country to support online learning, maintain kin, politically organize, and sustain independent journalism, small business, public safety, and positive messaging about Native American and Indigenous identities. Where research of the 1990s and 2000s relied on a trope of "cultural difference" to suggest that American Indians do not use the Internet by choice, evidence from the 2000s to the present suggests otherwise. Tribal communities dialogue about Internet privacy, cybersecurity, cybercrime, cultural assimilation, language shift, and online safety. Native Americans innovate in rural locations. Examples include the establishment of an emergency WAN to support uses of commercial drones and livestreaming by independent journalists at the *#NoDAPL* protests at Standing Rock [19], exploration of FM radio as an Internet delivery mechanism [84], solar panels to power towers along a network backbone by a tribal ISP in southern California [21], and savvy social media marketing by a women's cooperative to sustain a northern New Mexico jewelry market. [29]

4 METHODOLOGY

Our methodology is embodied through the Full-Circle Framework, which combines decolonizing and feminist ethics of care theories to guide an Indigenous feminist participatory approach to addressing digital divide challenges. We theorized the framework based on our prior experiences working with Indigenous and rural communities, and draw on Indigenous standards for research and knowledge work [74, 90, 94]. Our stakeholders focus on various "levels" of digital inequity, and include board members from REDINet, tribal librarians and community STEM champions, and tribal leaders who further tribal sovereignty through self-governance, education, and ancestral traditions. As researchers, our ethnographic approach cycles between observation and intervention, akin to what Michalowski and Dubisch term "observant participation" [55].

One set of standards that we draw on is the the First Nations Principles of OCAP, which focuses on the Ownership, Control, Access, and Protection of data related to sovereign Native nations [28]. OCAP acknowledges: (i) collective community ownership of data; (ii) the rights of tribes to seek control over all aspects of research and information management; (iii) the principle that tribes must have access to information and data about themselves regardless of where they are stored; and (iv) the physical stewardship of data and information must be determined in relationship with tribes. By integrating OCAP into our framework, we affirm the value of self-determination in addressing rural digital inequalities, and with regard to respectful and reciprocal relationships as we support community-centered generation, perception, and resolution of problem and design spaces.

4.1 Data Collection

We apply a range of methods to discern and characterize the digital divide in our partner communities. These include quantitative analysis of mobile broadband coverage data; mapping of Census data to indicate socioeconomic status through technology corridors and network routes; archival review of policy papers, newspaper articles, government press releases, government technical reports, and federal grant and loan applications and awards; qualitative analysis of interviews and conversations with stakeholders; ground-truth campaigns to validate existing connectivity measurements; digital ethnography; Indigenous storywork; and action-research based digital skills workshops. As our understanding of community needs and uses evolves, we address the divide using a bottom-up approach, starting with the deployment of first-mile network infrastructure aimed at providing physical access to the Internet in areas identified by our community partners. While the full reporting of results for each of these methods is beyond the scope of this particular article, in Section 5 we describe the specific methods used to elucidate findings selected for this publication. First, however, we describe in detail our overarching methodology, the Full-Circle Framework.

4.2 The Full-Circle Framework

Through four phases of concurrent processes of design and inquiry the Full-Circle Framework, depicted in Figure 2, stimulates community-centered innovation. In different ways, each phase directs research decisions such that the overarching inquiry is not just about the rural, but is also for the rural. The first phase requires understanding the sociotechnical landscape. The second phase leverages knowledge from the first phase to strategize for future infrastructure. The third phase is about infrastructural augmentation. In the fourth phase, the team reflects on research impacts, with the intent of refining design and refreshing lines of inquiry. Each phase includes research processes such as collecting and analyzing data, designing infrastructure, and communicating findings in accord with phase goals and responsiveness to community needs and asset-based

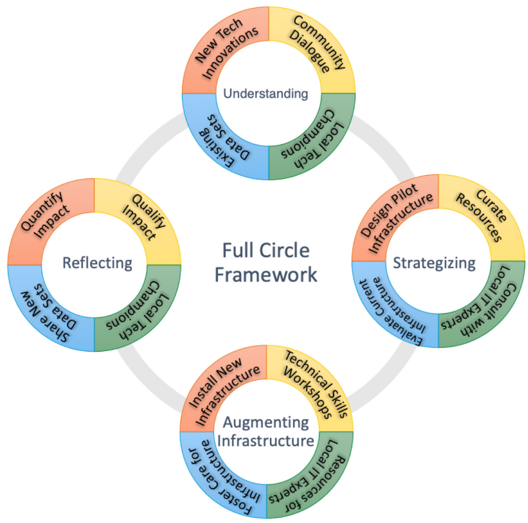


Fig. 2. Full-Circle Framework diagram.

capacities. The framework pivots on researchers maintaining reciprocal and ethical relationships with people who live in and care for a particular place. Thus, as researchers, we must continually confirm our relational role. This is extraordinarily important with regard to partnerships with sovereign Native nations, as tribal law prevents actions by researchers and non-tribal members on federally-recognized Indian land without express permission by tribal government representatives. Thus this framework is different from other community-based and participatory design models forwarded in HCI that position Indigenous peoples as ethnic minorities or underserved populations with whom the researcher must build rapport. When working with sovereign Native nations in the US, researchers must cohere to tribal laws about regulation of domestic activity, including research activities that shape social change, which is precisely the purpose of community-based and participatory approaches. Thus, the first step in the Full Circle Framework is that community stakeholders must invite researchers into the circle. Moreover, researchers must have their presence in the circle confirmed before progression to a new phase. Sometimes, the affirmation of researchers' relationship with community is confirmed through formal means of governance, such as approval by a tribal council. It is also affirmed through less formal methods, such as an invitation to participate in related efforts.

Moving through the diagram, the first phase is "Understanding," and work flows in a clockwise direction toward "Strategizing," "Augmenting Infrastructure," and "Reflecting." The four concurrent work processes are synergistic: technical research efforts (red), action research efforts (yellow), participatory engagement with tech champions to understand needs and boost skills (green), and citizen science engagement (blue). Goals and activities for each phase are described below.

4.2.1 Phase I: Understanding the Sociotechnical Landscape. At the beginning, it is integral to discern the complexity of the sociotechnical landscape. Digital ethnography and macrosociological and historiographic techniques permit characterization of critical factors and conditions, including histories of industrialization, the relationship between urban development and rurality, economies, demographic shifts, patterns in infrastructural innovations, and social histories. Thick description captures the social textures that distinguish communities' ways of life, which likewise reveal the catalysts of sociotechnical assemblages.

The research team's goal is to narrate the social textures of the sociotechnical landscape such that depictions of critical events and actors are recognizable to project partners. Narrative depictions can include descriptive paragraphs, visual representations, essays, vignettes, and journalistic description of key moments, events, individuals, and settings. Thereafter, focusing on the needs, goals and visions of partner communities requires participatory action research techniques, in which the observational and narrative skills of the researcher springboard dialogue, clarify perspectives, provide datasets, establish relationships, diagnose obstacles, and ideate interventions. The research team integrates these into the strategizing and augmenting phases of the framework.

4.2.2 Phase II: Strategizing for Future Infrastructure. After establishing a rich understanding of the problem space, community stakeholders may invite a research team to strategize. Strategizing involves parallel research and community engagement processes. Typically, strategizing involves consulting with local IT experts on their infrastructure and plans for growth. Local IT experts have the technical savvy to understand the histories, realities, and limitations of **information and communications technology (ICT)** infrastructure and are attuned to local information needs. They have informal or unpublished datasets and tacit knowledge about infrastructure. Additionally, they can also provide researchers with the access needed to measure infrastructure performance directly. This knowledge, data, and access enables researchers to evaluate infrastructures in processes grounded in community needs and experiences. Local IT experts are often part of the community and not part of a larger hierarchical entity that manages or governs the community. When working with rural tribal communities, this might mean that local IT experts are members of the tribe, live on (or near) tribal land, or are easily recognized by community members.

Simultaneously, researchers must survey new and existing technologies to augment infrastructure. This involves examining the physical properties of the technology (e.g., frequency and bandwidth capacity) while exploring technical standards and protocols developed around the technology, including licensing practices and power restrictions. The research team must design pilot infrastructure, including the development of system diagrams that synthesize data flows, devices, uses, and physical landscapes into an integrated vision.

Finally, strategizing requires curating resources to deploy new infrastructure. Curating resources includes fund-seeking and cultivating positive interpersonal relationships to sustain community-situated research. In many rural and tribal communities, healthy interpersonal relationships are the resource that ensure a project's momentum especially when other resources are limited [21, 73].

4.2.3 Phase III: Augmenting Infrastructure. Once a strategy is in place and has received stakeholder approval, a project can move to the implementation stage. We find ICT infrastructures to be an emergent texture within a greater social fabric. We thus refer to implementing and building infrastructural capacity as "infrastructural augmentation," to acknowledge how new technologies build upon preceding infrastructures, inclusive of ICT networks, energy grids, or the fundamental structural relationships between people, land, and institutions. As such, in phase III of the Full-Circle Framework, researchers must engage with community stakeholders and local IT personnel toward novel deployments.

Deploying new infrastructure consists of several processes, such as applying for usage licenses, ordering equipment, physical installation, testing, developing performance and usage measurement equipment and software, installing measurement equipment, and communicating updates with local governance bodies. All of these processes are driven by the physicality of ICT infrastructure, in the sense of equipment, but also with regard to manipulation of an environment (e.g., transmitting waves of energy across space) prone to interference. While some processes such as installation, are one-time occurrences, others such as obtaining licensing or updating equipment is recurrent. Researchers should help local IT experts form responsive relationships with equipment vendors and license-granting agencies. This ensures system sustainability and helps local IT experts build social capital for future augmentation.

Augmenting infrastructure also involves researchers engaging with community members around uses of infrastructure. This can be accomplished in many different ways, and community technology champions can guide appropriate approaches. One approach is to facilitate skills workshops that empower community members to monitor and evaluate existing and newly installed infrastructure. Another approach involves digital skills workshops for community members. A third approach is to engage community members in participatory design workshops to co-create meaningful tools and services. On a broader scale, it is also helpful to foster care about ICT infrastructure beyond the community immediately impacted by new ICT installations. By educating near neighbors about newly installed ICTs and their benefits, researchers can help develop an ecosystem of support to maintain infrastructure.

4.2.4 Phase IV: Reflecting on Research Impacts. After augmenting infrastructure with new technology, it is necessary for researchers and community partners to reflect on usage and performance of infrastructure, positive and negative impacts on community goals and values, and sociotechnical impacts.

One approach to reflection is through methodologically quantifying and qualitatively assessing the impacts of infrastructure. This can involve measuring infrastructure performance and usage and exploring any changes over time. From a qualitative perspective, this involves the research team practicing reflexivity at an individual level, as a team, and relationally, with regard to their project partners. As individuals, researchers consistently contemplate how their work with their project partners nuances and challenges their previous academic expertise and broadens their ways of knowing. As a team, the reflexive work occurs as they deepen their ethical and social commitments by choosing what new lines of inquiry to pursue, what to publish where, and how to craft findings in ways that are most beneficial to the needs of project partners. At a relational level, certainly it is known that the research changes the researcher, but in this case, it also changes the instantiation of the researched, namely, the design of infrastructures, but because network backbones are also made of regulatory processes, work practices, technical capacity, and the skills of users and personnel, the research team has a responsibility to craft findings in a way that shape future policy development and public understanding of infrastructures toward the ethical orientations defined by the project partners in their care for their communities. *On that point, we note that though the findings of our research project are laid out in a linear fashion for purposes of legibility in the scientific method of publication, the iterative and reflexive process of the Full Circle Framework actually means that we are constantly cycling through the four phases of understanding, strategizing, augmenting, and reflecting. Our linear presentation of findings should thus not be interpreted as a phase-by-phase accumulation of findings, but rather, should be understood as an organized assembly of results for the purpose of clarifying the function and usefulness of the Full Circle Framework in our particular research context.*

While the Full-Circle Framework is related to iterative approaches used in CBPR and PAR, it is distinctive for its orientation around tribal sovereignty as a polar axis, where sovereignty is a dynamic force that invites and repels research collaboration, and where multiple iterative projects develop and sustain tribal sovereignty as they build on each other and accumulate resources. While Figure 2 illustrates a single iteration through the phases of the framework, we note that the long-term (on the order of decades and centuries) goal of the framework is to grow and strengthen tribal sovereignty over multiple iterations. A visualization of this unique orientation and growth pattern is shown in Figure 3. An example of this growth is when researchers are invited back

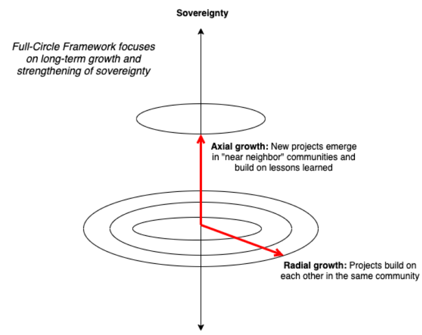


Fig. 3. Orientation and growth pattern of iterative cycles through the Full-Circle Framework.

to a community to engage in a sociotechnical project with an altered scope. Another example is when adjacent communities (geographically or socially) invite researchers to collaborate on sociotechnical projects around tribal sovereignty based on observations of engagement in similar communities. *Thus, through sustained engagement with the Full-Circle Framework, researchers become part of the social fabric of the rural landscape, weaving together actors from different parts of the network so as to increase and strengthen near-neighbor relationships across spatial, temporal, and cultural dimensions.*

5 PUEBLOCONNECT: APPLYING THE FULL-CIRCLE FRAMEWORK TO CHARACTERIZE AND ENHANCE INTERNET CONNECTIVITY IN NORTHERN NEW MEXICO

In this section, we describe how we apply the Full-Circle Framework to characterize and enhance Internet connectivity through the PuebloConnect project. PuebloConnect is funded by the National Science Foundation, and brings together social scientists, computer scientists, community Internet champions, and REDINet to address “the dual goals of improving Internet access in economically marginalized communities while also building local capacity towards regular digital content creation” in northern New Mexico [58]. As of this writing, PuebloConnect is at the midpoint of a three-year project cycle. In this section, we report the findings of an ongoing digital ethnography of the sociotechnical landscape in northern New Mexico, and interweave our characterization with thick description of the social textures and technical design decisions around TVWS deployment and spectrum-related process. Our findings reveal social, technical, geographic, and political conditions that influence how Internet infrastructure in rural northern New Mexico evolves.

5.1 Phase I: Understanding the Sociotechnical Landscape

The sociotechnical landscape of northern New Mexico is the locus around which all of our technical and social scientific research methodologies orient. To give a sense of the responsibility of our research partners, first we qualitatively contextualize the nature of work through REDINet. Then, to give a sense of the relational richness around Internet access, connectivity and use in the landscape, we describe how a tribal housing authority in the region has championed deploying last-mile connectivity.

Qualitative work—in particular PAR approaches to building rapport and establishing relationships—is key to this phase. A precept of Indigenous storywork is the acknowledgement of existing common relationships toward the establishment of new and renewed relationships. It is an epistemic coming together, and an acknowledgement of the pluriverse of lifeworlds that enrich the directionality of complex sociotechnical assemblages. We conducted open-ended interviews and engaged in conversations and dialogues in the spirit of Indigenous storywork with local tech champions. [90, 94]

We shared stories about colonial technologies with Raymond Ortiz, IT specialist for Rio Arriba County, over lunch at a Mexican market in Española. We talked story with Jennifer Case Nevarez about the significance of Native science teachings for Native youth while driving the highway bisecting ancestral Pueblo landscapes. We discussed the extreme technical needs of local arts organizations while touring the historic colonial district of Santa Fe. We made impromptu visits to the hilltop Los Alamos National Lab Foundation where we scanned the physical terrain of the city of Española and nearby Santa Clara Pueblo, placing anecdotes about infrastructural breakdowns that shut down service to entire regions for days. We discussed the challenges of developing tribal libraries as anchor institutions with Faye Hadley, the state liaision for tribal libraries. We attended packed meetings with American Indian studies educators and state legislators as they sorted out the cost of providing learning technologies to anchor institutions that support distinctly Indigenous pedagogies. We noted physical features of the landscape that indicate class difference, segregation, cultural histories, population density, and tribal territories as all of these are also indicators of the socioeconomic aspects that shape regional digital divides. We identified people and groups we know in common with our partners in an effort to construct our location in a shared social fabric.

We also applied digital ethnographic methods of observation as we visited key sociotechnical locations, including REDINet headquarters and tribal libraries, and observed features of the northern New Mexican landscape that our tech champion partners identified as challenges specifically shaping infrastructural deployment: hilly rocky regions; jurisdictional boundaries; expanses of undeveloped, BLM regions, and private land; and urban, semi-urban, and rural municipalities. By traveling through these regions with our partners, we were able to see as they see, noting the technical, social, cultural, and political significance of places. We combined these embodied, tacit, and social ways of knowing with archival review of records indicating features of the regional landscape—physical and population maps, news articles about regional technology advances, and public descriptions about key anchor institutions—to identify the textures of the social fabric that we collectively characterized with our various project partners and regional tech experts. Thus, while a social fabric can be diagrammed by a social scientist as a kind of network or typology of influential actors and institutions, *the social texture of that fabric is rendered through oral storywork and deep listening, and manifests in narrative thick description.* Thus when we liken the community-driven construction of an emergent network infrastructure to a squash plant, we are also reminding our readers of the curling vines of an indigenous crop that grows by human hands and natural rhythm alongside the sun-warm ancestral adobe walls of northern New Mexico homes. The metaphor invokes the ancestry, inheritance, cultivation, care, nourishment, and terrain, all of which relate to the dynamics of the cooperative network infrastructure. Thus, in the tradition of feminist action research and emancipatory PAR from the global south, we discerned technical barriers to middle-mile advancement alongside social and political inequities that impede Internet access and connectivity. [66]

5.1.1 Establishing Trust with Local Tech Champions. Prior HCI work notes the integral role of trust in participatory and community-based research. [81] For Indigenous research methods, trust-as-reciprocity is the starting point of any project. [74, 90, 94] In November of 2018, we presented our research plan at a REDINet board meeting outside of Santa Fe. Though we had been co-developing aspects of the plan with different members of REDINet through emails and Skype calls, the entire partnership had yet to meet in person and properly introduce themselves.

We introduced ourselves as a team of women scientists and community tech champions—some of whom bear Indigenous ancestry—who have been working over the years within Indian Country and we acknowledged coming into their space, the work space of industry practitioners who also play key roles in their sovereign tribal and county governments. Formal relational introductions are an extraordinarily important protocol in Indian Country. This style of introduction is a kind of antidote and deterrent to the colonial behaviors of university researchers who exploit their institutional power by swooping into tribal communities to disrespectfully mine data for hypotheses and projects that are ultimately self-serving [74]. Our project partners were keenly aware of the sovereign rights of tribes with regard to research. Indeed, months before the partnership kick-off, Pojoaque Pueblo had established a land-based heritage program, requiring any excavation or construction in any of the historical lands of the Tewa people—including state lands—to undergo review by the tribe's Traditional Historic Preservation Officer [6]. The agreement was years in the making, and required a great deal of conscientious relational labor. Thus it was no surprise that when we began our introductions, board members informed us that they had already researched our online profiles and record of work.

Importantly, research that values Indigenous knowledge and the self-determination of sovereign governments requires that each researcher—even the Indigenous ones—state their motive for pursuing the work, their family origin and lineage and any connections to the local community, and their moral orientation to the work. We were clear that our moral orientation included respect for tribal sovereignty, and those of us who had established prior research or educational partnerships with the tribes and communities in question shared evidence of our accountability. Indeed, we had prepared a packet for the team that included step-by-step indications of how aspects of the project and human subjects review process relate to the sovereign rights of the tribes. This level of assurance is integral to reciprocal and respectful research relationships in Indian Country, and indeed, is also integral to research with populations and communities that are often misrepresented and misunderstood. Thus, we also accounted for the quasi-sovereign status of the Hispano community of northern New Mexico as it is guided by acequia practices, qualities of DIY resourcefulness, and a keen awareness of regional cycles of colonial imposition and shared environment with the Pueblo peoples.

Ultimately, through the candor of the meeting, we established multiple relational agreements, and began discerning sociotechnical nuances of the environment as well as potential novel IT infrastructures for the region, including TVWS, **Educational Broadcasting Services (EBS)** spectrum, and **Citizen Broadband Radio Services (CBRS)** spectrum. PuebloConnect hinges on the communicative effectiveness and trustworthiness of our partnership. For months thereafter, a series of phone calls, meetings, site visits, and email threads ensued through which we carefully ascertained features of the existing technical ecology, and merged those insights with our collective knowledge from prior work.

5.1.2 Contextualizing REDINet. Initiated in 2010, REDINet is a joint powers agreement among seven governments. It emerged from a 10.5 million dollar investment for a middle-mile high-speed broadband network for northern New Mexico from the American Recovery and Reinvestment Act. In the mid-2000s, a consortium of governments, including the intertribal All Pueblo Council of Governors, ideated REDINet to support economic development through high-value agriculture, media, renewable energy, and the outdoor recreation industry. The funds were disbursed through the Northern New Mexico Economic Development District, and included an additional two million dollars in investments from Rio Arriba County and Los Alamos County, and Ohkay Owingeh, Pojoaque Pueblo, Tesuque Pueblo, and Santa Clara Pueblo. At the time of its formation, residents were largely relying on dial-up Internet service. The goal of REDINet was to deploy 142 miles of fiber, connect at least 115 anchor institutions, provide high-speed bandwidth where none was available, offer multiple options for data transport, and increase ISP access to new markets, which would result in lower subscription costs per user. Partners that supported 4.3 million dollars in matching funds included middle and last mile ISPs as well as others reliant on high speed data transmission, including Jemez Mountains Electric Cooperative, Kit Carson Electric Cooperative and Telecom, Rio Arriba County, Los Alamos County, the City of Española, Northern New Mexico College, and Los Alamos National Security.

A decade since the signing of the joint powers agreement, REDINet connects over 75 anchor institutions, and the board members hope to connect more. Yet the planning to do so is shaped by the rural textures of life that characterize the region. On New Year's Day in 2019, ISP Black Mesa Wireless reported to its customers how a single celebratory shotgun pellet damaged a REDINet fiber optic cable at 12:01 am. To find the damage, in the middle of the bone-chilling winter, REDINet techs manually inspected hundreds of feet of fiber across high desert terrain using a bucket truck, which extended the time of the outage, and required that customers receive credits for the billed downtime. Two weeks later, a power outage affecting REDINet shut down Internet service for the entire city of Española. A former general manager of REDINet described other unexpected instances shaping build-out, including theft of cables, and the costs of trenching in alternatively rocky or sandy terrain. Indeed, during a 2018 visit with the board, the board members laughed at the often challenging role of what they termed the "very general" general managerial role. Decisions undergo numerous processes of approval through Rio Arriba County leadership as well as tribal leadership. Tribal leaders are also charged with protecting sacred spaces and upholding the privacy undergirding tribal self-determination. Approval processes require aligning values around the community's perceived Internet need, social goals, and allocation of capital funds.

Acquiring capital to improve services to sometimes remote locations, across tribal jurisdictions, and with regard for the needs of low- or no-income anchor institutions amid the goals of major telecom competitors is like piecing together a quilt with insufficient thread. Raymond Ortiz, a REDINet network administrator, described an instance when the network shut down resulting in young people in Española not having Internet at home for three days. He described how for an at-risk youth, not being able to do homework for three days can result in falling behind in school, which over time, accumulates into fewer future opportunities for rural New Mexico youth. As Yazzie/Martinez v. State of New Mexico recently revealed evidence of structural discrimination of Hispano and Native American students from pre-K through college, including lack of access to digital infrastructure and programs through the public education system, these kinds of anecdotes are alarming, yet for those research team members who spent our formative years in the state, familiar. Meanwhile, in stark comparison, prior to the pandemic, the city of Santa Fe invested millions in digital infrastructure around the for-profit arts and entertainment enterprise Meow Wolf, including a rumored dedicated line for transmitting high-resolution virtual reality content from Meow Wolf's Santa Fe studio to design studios in Los Angeles. Thus, the board members of REDINet articulate a future-oriented vision for middle-mile and first-mile network advancement that is tempered by the realities of the social and physical geography of the areas they seek to connect, regional economic limitations, awareness of the high costs of infrastructural investment, and an openness to piloting new systems and devices—such as snap-on fiber optic connectors—to increase the operating capacity of their existing assemblage. Meanwhile, they retain full-time jobs working for their various governments, overseeing projects adjacent to REDINet advancement.

Sociotechnical aspects of REDINet operations reveal the boundary-spanning work of its operators and administrators, confirming what prior studies assert: that Internet connectivity in rural regions are shaped by historical patterns of economic disenfranchisement; distinctive goals around the purposes of Internet for different communities, including tribes and rural communities; limited numbers of skilled personnel to carry out complex projects; and the ability of project leaders to advance specific portions of the network over time through a combination of government grants and loans programs and entrepreneurship.

5.1.3 Tribal Housing Authority Championing Last Mile Connectivity. In 2012, Senator Tom Udall announced that in light of 47% of New Mexico's rural residents (approximately 220,000 people) lacking a reliable Internet connection, broadband and telecom providers Century Link and Windstream would receive 2.3 million dollars as phase 1 deployment of the **Connect America Fund (CAF)** program [80]. The FCC promulgated CAF to subsidize costly network build-out in rural areas; in 2012 the goal was to connect 19 million unserved rural Americans by 2020. In 2019, however, Windstream filed for bankruptcy [11, 14]. Local residents and ISPs assert that Windstream did not prioritize the most underserved communities. Tracking the bankruptcy reveals how community network provider competition with major broadband corporations over federal dollars may also result in gaps that affect the operations of rural ISPs and anchor institutions.

End-users pay for the loss of infrastructures and services. Many residents in rural New Mexico rely on tribal schools and libraries for Internet access, and though public schools and libraries qualify for e-rate funds, getting tribal schools and libraries the e-rate designation is a bureaucratic challenge [33, 43]. Furthermore, tribal libraries and schools operate with limited personnel; most tribal libraries are only open part-time, offering limited Internet access for their communities, and also limiting the time that leadership can complete grant applications [42]. Similarly, tribal schools target their students on a limited basis, and do not necessarily focus on the information needs of surrounding families or communities. In the midst of these gaps—gaps in federal funding, lack of federal coordination with state and regional grant and broadband plans, limited personnel, high costs of rural network deployments amid regions with many low-income residents—ICT champions innovate Internet connectivity and access for their communities. In the mid-2010s, the tribal leadership of Santa Clara Pueblo began planning for increased Internet connectivity and access on the reservation through focusing on anchor institutions, including the Santa Clara Pueblo Community Library. In 2017, Librarian Teresa Naranjo noted how "only about 50 percent of the pueblo has a computer at home, and the number with Internet access is even lower" [5]. As part of the Pueblo-Connect project, in 2019, Case Nevarez and Naranjo met to host digital skill building workshops for the community. Case Nevarez confirmed what tribal librarians have previously noted regarding the challenge of hosting community-centered digital skills workshops: many times, only a few individuals show up, and if they do not have a computer and Internet connection in the home, it is difficult to practice skills [43]. It is very much a step-by-step person-by-person process. Nevarez also noted the distinctive goals of those working toward digital skill development through the tribal schools and those working in the library, and interestingly, in Santa Clara, ICT champions working through the **Santa Clara Pueblo Housing Authority (SCPHA)**.

Indeed, Francisco Simbana, Executive Director of the SCPHA, is a tribal ICT champion. As part of the SCPHA affordable housing mission, Simbana began pursuing affordable Internet access for its residents. At present, rates are 35 dollars a month per unit, which is made possible by revenues gained from the SCPHA laundromat. A major focus of the SCPHA Internet service plan is related to an associated mission to provide a full-time summer program and year-long after-school program for young residents that incorporates informal learning, childcare, and technology awareness. The Community Learning Network thus partnered with SCPHA to fund a youth robotics program, in which two children won in their category in 2018. Simbana has a vision for the long-term positive social development of the young people enrolled in the SCPHA programs, and so finds ways to fund a computer lab, schedules guest speakers, and before the tribe closed the reservation to non-residents, had been working with Case Nevarez to support a program around social games made by Indigenous game designers, including games like NeverAlone and When Rivers Were Trails [47, 53]. Through these efforts, Nevarez identifies another integral skill of tribal ICT champions, and that is a loving and genuine nature that builds and sustains the relationships needed to cut through many potential barriers. In Indian Country, strong values around self-governance, self-determination, Indigenous ways of knowing, and cultural revitalization require that educators working toward technical capacity-building—including digital literacy for network end-users—plan in step with the place-based cosmovisions and relational economies that shape, in this case, Puebloan ways of knowing through the multicultural landscapes of northern New Mexico.

5.2 Phase II: Strategizing for Future Infrastructure

After establishing a nuanced understanding of the sociotechnical landscape and the possible network technologies that could be deployed as last-mile connectivity solutions, we ideated community needs for ICT infrastructure and aligned these with technical and social research questions. We began by consulting IT experts who work within the northern New Mexico region. We then identified and selecting novel technical infrastructure that meets local needs—in this case, TVWS solutions, and then measured the existing ICT infrastructure in the region—availability of spectrum for TVWS solutions.

5.2.1 Consulting Local IT Experts & Curating Resources. Shortly after our initial in-person meeting with the IT experts on the REDINet board, we agreed upon a plan for working strategically with the Pueblos to deploy last-mile Internet capacity within the constraints of the PuebloConnect project budget. Ultimately, we decided to deploy and test new wireless technology in phases with one Pueblo initially piloting the equipment with a small number of homes connected to the newly deployed base station. Having recently adopted community-wide Internet improvement goals, Santa Clara Pueblo, led by IT professional and REDINet board member Jerrold Baca, offered to be the "pilot" for the PuebloConnect project.

In order to learn more about Santa Clara Pueblo's vision for first-mile ICT infrastructure, we invited Mr. Baca to join our team at a National Science Foundation meeting in Denver, CO. The meeting co-convened with a national smart city technology exhibition, which provided a useful environment for discussing potential technologies for connecting village homes in Santa Clara Pueblo to the REDINet middle-mile fiber. As we walked through the exhibition with Mr. Baca, we examined demonstrations of potential wireless technologies, including millimeter wave mesh networks, small-scale cellular networks that operated over 2.5 GHz EBS spectrum and 3.5 GHz CBRS spectrum, licensed microwave mesh, and TVWS. Mr. Baca informed us about two concerns that needed to be considered when selecting a last-mile technology. The first concern was cultural, wherein Santa Clara Pueblo (like many other Pueblos) did not want to have any ICT installation that "crossed the horizon" in the plaza, the traditional and ceremonial center of the community. Since the homes that needed to be connected were located around the plaza, this ruled out wireless technologies that would require many base stations located close to the plaza center. The second concern was that homes around the plaza that needed Internet connectivity were built from adobe brick, 10+ inch traditional mud brick, which can cause significant wireless signal attenuation. These concerns were critical for strategic planning as they presented community constraints that impacted technology deployment decisions and that were not obvious to the research team.

5.2.2 Conceptualizing Infrastructure & Technology Research. Based on our conversations with REDINet IT experts and the needs for extended wireless connectivity through some of the ancestral adobe villages in the Pueblos, we decided to leverage the TVWS, which refers to the unused wireless channels of spectrum that exist between television station broadcasts [27]. In 2010, the

FCC adopted policies to allow unlicensed usage of TVWS with the hopes of enabling a wide range of services and products, including WiFi using the 802.11af standard. TVWS operates in the upper ultra high frequency 700 MHz band, ranging from 698 to 806 MHz. The wavelength of spectrum at these frequencies enables robust transmissions over long distances and allows signals to penetrate through foliage and buildings. This makes it an ideal technology for bridging first-mile digital divides in rural areas, where there is often more white spaces available for transmission. More importantly, the longer spectrum wavelength that TVWS uses enables wireless signals to penetrate thick adobe walls and foliage in a way that competing wireless technologies that use higher frequency spectrum (e.g., 2.5 GHz EBS and 3.5 GHz CBRS) would not be be able to. Given that TVWS base stations have been available for purchase from several vendors in the United States for several years, we felt it was feasible to work with our partners in a three year time frame to deploy new TVWS infrastructure and ensure that it was an option that actually worked to extend Internet connectivity.

While TVWS has been touted as a promising solution for first-mile rural broadband [17, 56, 59], the lack of measurements surrounding performance and usage of real-world deployments has caused a lag in interest from the networking research community. Beyond providing first-mile Internet connectivity to the four Pueblos, one of the goals for the PuebloConnect project was to characterize usage and performance across the full network stack. Thus, the research questions dovetailed with community needs: the REDINet Pueblos had a need for increased first-mile Internet availability and the research team had a need to measure the performance of a "live TVWS network."

5.2.3 Evaluating TVWS Availability. When a TVWS base station is deployed, it contacts a global database and provides information—such as its geographic location and elevation—for permission to operate. Without permission, the base station will not serve client devices. Typically rural regions have fairly open spectrum due to the lack of incumbent transmitters. Unfortunately, interfacing with the database is complex and often not possible for users; the equipment vendor had to query the database on our behalf to find open channels.

Through this process, we encountered the first of many roadblocks. There were not three contiguous channels available for use; in fact, there was only one available channel in the entire spectrum. Figure 4 shows a screenshot from the database revealing available TVWS channels. While the exact reason for this was difficult to discern, we learned that an astronomy radio band covers the entire Santa Clara Pueblo, and that transmission was prohibited in those bands. There was also some question as to whether the high number of TV transmitters in the Albuquerque region was impacting available spectrum in our deployment zone. In this case, the matter of spectrum availability over tribal lands is important with regard to a sovereign tribal right to airwaves and the social impact of astronomical research on Indigenous peoples and lands [8, 93].

Our research team decided to probe these potential spectrum conflicts by collecting spectrum usage measurements. Our goal was to discern the extent to which the licensed spectrum was being used, at which we point we could evaluate the feasibility of a TVWS solution. From May 25 to June 3, 2019, we measured spectrum usage in the region, particularly in the Santa Clara Pueblo. Diverse rural landscapes necessitated a combination of spectrum measurement methodologies, including a driving spectrometer, an **unmanned aerial vehicle (UAV)** spectrometer, and a static spectrometer, depicted in Figure 5. We needed to capture fluctuations in spectrum usage over time. By evaluating spectrum usage across space, place, and time, we developed a holistic picture of spectrum availability in the area and ultimately determined the feasibility of deploying TVWS in Santa Clara Pueblo without interfering with incumbent traffic.

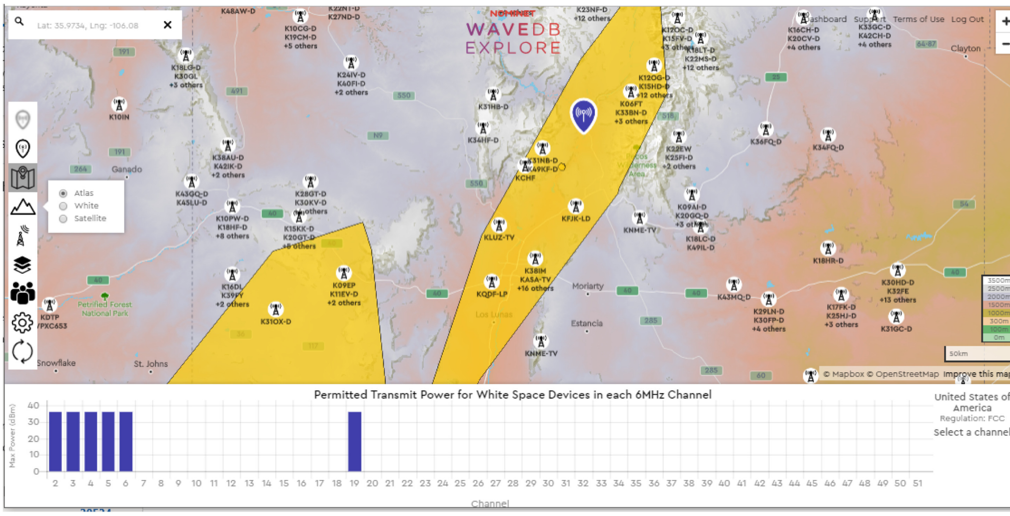
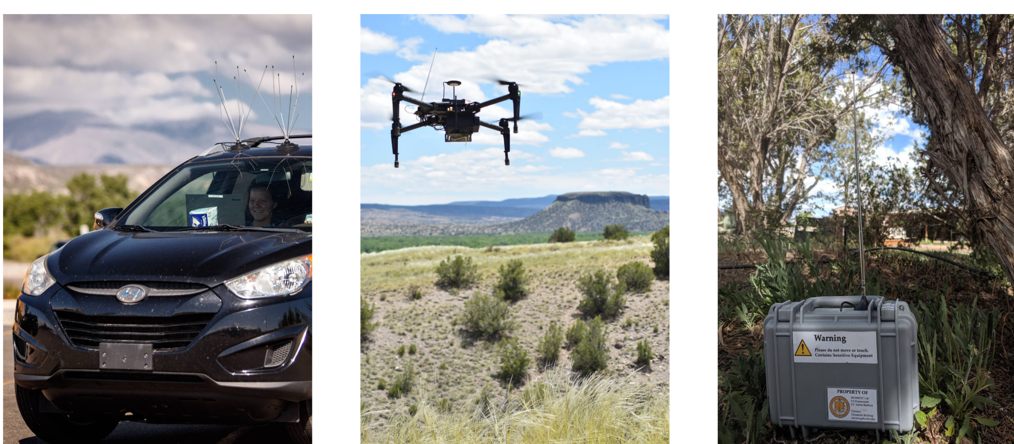


Fig. 4. Screenshot of Nominet WaveDB Explorer records for Santa Clara Pueblo. The blue pin represents the location where a TVWS base station would potentially be deployed. The black towers represent TV and radio broadcast stations. The bars on the bottom of the map show the strength at which a base station could transmit in each channel, thus a larger bar means that the channel is available. According to Nominet WaveDB Explorer, only channel 19 is available in the Santa Clara Pueblo area. Note that only channels 14-51 are considered to be usable for TVWS.



(a) Driving spectrometer (b) UAV spectrometer (c) Static spectrometer

Fig. 5. Different spectrum measurement methodologies used to measure TVWS spectrum availability.

We used two different mobile scanning methodologies to measure spectrum usage across space: wardriving and "warflying" techniques. Wardriving involved driving at 10 miles per hour through residential areas where TVWS would potentially be used as a first-mile technology and using a spectrometer connected to Ham radio antennas to measure the received signal strength on different channels in the 700 MHz spectrum band (see Figure 5(a)). Given the dirt roads and long distances between areas of interest, we supplemented our wardriving efforts with the novel technique of warflying, which involved mounting a spectrometer on a UAV and flying at a uniform altitude to measure received signal strength[3] (see Figure 5(b)). While the TVWS database reports that only channel 19 is usable in the Santa Clara Pueblo area, our measurements revealed that received signal strength was strong enough to cause interference with any TVWS transmissions on only two channels.

To measure spectrum availability over time, we placed ruggedized static spectrometers in locations where TVWS base stations might be deployed (see Figure 5(c)). These spectrometers remained in place over a 3-day period. By measuring fluctuations in availability over time, we were able to discern whether a TVWS installation in Santa Clara Pueblo would be likely to interfere with incumbent users throughout the day. We found that there were no observable fluctuations over a time period that included two days during the business week and one day during the weekend, which indicated that a new base station would likely not cause any interference with existing transmissions.

5.2.4 Evaluating Existing Mobile Broadband Infrastructure. Pilot infrastructure that extends REDINet's coverage using TVWS links allows the extension of fixed broadband services to specific locations. Mobile broadband services accessible via cellular access are also a critical component of Internet infrastructure as these services represent a scalable way to deploy Internet connectivity over wide areas of space. Indeed, in some rural areas, mobile broadband is the only means of Internet access, though the deployment of mobile broadband infrastructure still lags in rural tribal communities [24]. Unfortunately, the availability of this critical infrastructure is prone to overestimation by the FCC, particularly in rural areas [2, 9, 23, 68]. This is problematic as it can prevent state and federal resources from being allocated to communities that lack mobile broadband connectivity.

In April 2019, a representative from a mobile ISP approached the IT department at Santa Clara Pueblo with an offer to start a contract to be the Pueblo's "provider of choice." The ISP claimed that they provided better coverage than the existing provider used by tribal officials. The director of the Santa Clara Pueblo IT department reached out to our research team to see if we could evaluate these coverage claims in addition to evaluating the availability of TVWS spectrum. As we discussed the state of cellular coverage with our partners from REDINet, we learned that local residents had an abundance of anecdotal evidence of dubious coverage claims by many mobile ISPs. Thus, to substantiate anecdotal claims through quantitative ground truth evidence, we decided to systematically evaluate the coverage provided by all major ISPs that offered mobile broadband services in the area.

We collected ground truth measurements of LTE signal strength and throughput from four different providers using a variety of methods, including driving and UAV spectrometers to measure received signal strength power on different channels. Since there are so many different LTE channels, we used a static spectrometer to calibrate our mobile spectrometer methods. A static spectrometer was used to detect transmissions on any LTE channel in the area. We used this initial measurement to generate a list of frequencies that could be programmed into the mobile spectrometers (Figure 5(a) and 5(b)) to scan repeatedly as they moved across space. By providing this initial list of frequencies, it ensured that mobile spectrometers were able to maximize their time scanning frequencies that were actually usable in the region, and not measuring spectrum where no base stations would have been transmitting.

To understand how our mobile measurements with more sensitive antennas might correspond to a user experience of mobile broadband connectivity, we also collected measurements of LTE

[3]In a separate work, we demonstrated that warflying provides accurate measurements of received signal strength if it is calibrated to on-the-ground measurements [60].

availability using user end devices. To do this, we obtained two prepaid SIM cards for each provider as a means for connecting into the different mobile networks. After activating the SIM cards, we obtained the measurements. A subsequent analysis of our data revealed significant discrepancies between the ground truth measurements we collected and FCC coverage reports. For the leading mobile ISP, (which we measured as providing coverage in the largest number of Census blocks), we found that 81% of the Census blocks that we identified as "uncovered" through ground truth measurement were reported as covered by the ISP.[4] The significant discrepancy between ground truth measurements and FCC-reported coverage in rural and tribal areas contributes to the pernicious structural digital inequalities experienced by these communities. It also demonstrates how rural computing researchers might support Internet access advocacy efforts through systemic community-based data collection and analysis.

We find it noteworthy to describe the surprisingly difficult process of obtaining SIM cards. It took us a total of 24 active hours spent in three cities across two states to obtain the necessary SIM cards. Many kiosks only sold SIM cards from certain providers, or did not sell prepaid options. It took an additional 24 hours to ensure that the SIM cards were correctly activated and were able to access the LTE network of each provider. Similar to the lack of TVWS availability, the exact reason for the difficulty in obtaining and activating SIM cards was difficult to discern, but causes us to reflect on structures shaping digital inequality and process challenges in rural computing generally, and through the northern New Mexico landscape.

5.3 Phase III: Augmenting Infrastructure

After measuring TVWS availability and finding that there were indeed usable channels, we moved forward with our strategy for installing new TVWS infrastructure. In this section, we describe the installation process and associated layers of decision points.

5.3.1 Installing TVWS First-mile Connectivity. The installation process involves two major subphases of installation preparation and physical installation.

Preparing for TVWS installation. After exploring multiple TVWS equipment vendors, we selected 6Harmonics due to their combination of excellent reputation, eagerness to assist us, physical and medium access control layer protocols and characteristics, and ability to conduct the types of performance measurements we planned. Based on the limited availability of open spectrum channels in the Santa Clara Pueblo (see Section 5.2.3), our next step was to contact the FCC, to see whether anything could be done to facilitate a deployment. Our first point of contact was the FCC Office of Native American Affairs and Policy. After much consultation, we were instructed to apply for an Experimental FCC license, which would give us permission to transmit in a pre-defined location with pre-specified equipment, and would allow us to bypass the Nominet database query that would have stopped the base station operation.

The process of applying for an Experimental FCC license proved to be a second significant challenge. The online application process is complex. For instance, the multi-page application has multiple "dead ends," in which it is not clear how to submit the requested information and what step to take next. It also requires the input of the location of the transmission as well as detailed information about the transmitting device such as antenna orientation in the horizontal and vertical planes; beam width at the half-power point; frequency of transmission; output power/ERP; frequency tolerance; and a variety of other information not easily known by most users or installers. Fortunately, the 6Harmonics vendor was extremely helpful in providing much of this information.

[4]There was no disagreement about areas that were measured as covered by ground truth measurements.

In the end, the application was only successfully submitted after a multi-hour phone call with our FCC contact. It is unlikely we would have been able to successfully apply without this assistance.

Installing TVWS in Santa Clara Pueblo. The TVWS base station for Santa Clara was deployed onto a pre-existing tower outside of a Santa Clara Pueblo community building. Per the restrictions of the experimental license, it sits at just over 6 meters on the tower. The tower has a line of sight connection down the main road in Santa Clara for about a quarter mile before it becomes blocked by houses, tribal offices, and trees. Even with the base station powered-on, though, we experienced a stall in getting the **customer premise equipment (CPEs)** installed into homes. At the time, the Santa Clara tribal council was deliberating about which homes would receive the CPEs and subsequent Internet connectivity.

This is not an easy decision. Questions about which homes to select can relate to matters of domestic regulation, privacy, and academic achievement among other considerations. Community leadership deliberation on the benefits of Internet connectivity resonates with the discourse around third-level digital divides, and illustrates how self-governing rural communities consider these when distributing limited resources. During this stage of deliberation, social distancing mandates and school closures associated with both Santa Clara Pueblo's and New Mexico's response to the COVID-19 pandemic led the tribal council and the Santa Clara Pueblo IT department to pursue another strategy: mobile hotspots for drive-up Internet access. As the effects of the pandemic worsened in the region, our project partners shifted their energy to emergency situatedness: supplying PPE to community centers and clinics, identifying community hotspots and supplying Google Chromebooks to students as available, pushing for extensions to the August FCC deadline for tribal 2.5 GHz license applications, and working with the state to identify every family with schoolchildren who lacked a reliable Internet connection. Ultimately, a group of technologists from the Information Technology Disaster Resource Center deployed a series of short-term 2.5 GHz wireless solutions to existing fiber-optic and wireless networks in an attempt to mitigate connectivity gaps.

5.4 Phases I & II (Again): Re-orienting During a Global Pandemic

Only two weeks after installing the TVWS base station in Santa Clara, the COVID-19 pandemic led to school closures, shelter-in-place orders, closure of Pueblo borders, and university travel restrictions. At the time of writing, the Pueblos in New Mexico have experienced a first wave of severe outbreaks of COVID-19, have negotiated and distributed federal CARES Act funds, and are preparing for a second wave through the coming winter. We have placed many of our original research objectives on hold, and have begun to redirect our work toward community disaster resilience. Lack of Internet access is urgent as social distancing, telecommuting, and school closures are now in effect. As fellow Indian Country technologist Matt Rantanen recently noted, the COVID-19 crisis has turned the issue of a homework gap in Indian Country to one of an access-to-education gap. [67]

Due to this dramatic shift in circumstances, we transitioned to Phases I and II. Our strategies for ICT infrastructure deployment no longer made sense. Indeed, as shelter-in-place orders forced individuals and families to work, order groceries, and engage in online schooling from home, selecting a single family to receive a TVWS CPE when so many were in dire need became an impossible choice, especially as pandemic-related manufacturing and shipping delays prevented new equipment from being rapidly delivered to Santa Clara Pueblo. Indeed, an expected vendor's delivery date of a couple of weeks has turned into months. In order to move forward with the goal of extending Internet connectivity, we needed to shift to a posture of careful observation as the sociotechnical landscape had been radically altered by new daily realities. We also worked with our partners to try to strategize the best ways to pivot our project aims to provide assistance for our partner communities during a severe long-term crisis.

5.4.1 Supporting Applications for Emergency Usage of 2.5 GHz Spectrum. On March 30, 2020, the FCC announced that it was granting temporary spectrum access to support tribal Internet connectivity during the COVID-19 pandemic [26]. In light of this, our partners at Santa Clara Pueblo submitted an application for a Special Temporary Authority license for the 2.5 GHz spectrum to enable increased capacity for last-mile distribution of Internet connectivity. As part of documentation that was being used to support the license application, measurements of LTE access we collected in 2019 (which ran counter to claims of LTE availability as reported by the FCC) were used as evidence of lack of coverage.

5.4.2 Surveying Community Internet Connectivity, Access and Uses for Emergency Hotspot Deployment and Long-term Planning. Before COVID-19 physical distancing and telecommuting requirements, each project partner functioned like an ICT jack-of-all-trades, supporting policy and regulatory work, IT services, network administration, grant and loan opportunities, and technical maintenance for their separate communities. The sudden and unexpected physical distancing requirements exacerbated the urgency of their tasks, as they sought to rapidly deploy WiFi hotspots to support the distance learning needs of K-12 and college students as well as telecommuting employees. Before COVID-19, many of our project communities relied on intergenerational tacit knowledge of their communities and landscapes to ascertain underserved regions and optimal locations for network deployment. Indeed, this is the essence of Indigenous network administration: such knowledge is optimal for these particular communities. However, emergency hotspot deployment stimulated a need to know the specific ISPs, perceived quality of service, access to computing, and likely bandwidth needs of each household across the reservations. Thus our team is in the process of designing and deploying a 5-minute survey of community Internet connectivity, access, and uses, the results of which can be used for immediate and long-term planning, from placement of emergency TVWS drive-up hotspots to location of fiber to extend services via 2.5 GHz spectrum. Indeed, before public health dictated stay-at-home orders, the overarching findings of our work indicated the the need for policy interventions such as community-based verification of federal datasets about airwaves, an FCC priority for tribal emergency WiFi hotspots, and minimum Internet specifications and digital literacy standards for schools and libraries serving Native American and Hispanic students. In the midst of the crisis, the implications of these findings are laid bare as we note how major ISPs in cities have been able to distribute low-cost subscription plans while boosting bandwidth per household, and as we wait for evidence of K-12 and college student academic achievement measures from rural communities. Indeed, during this writing, Santa Fe Indian School suspended online learning due to low rates of Internet access among students, and scenarios in which students were rapidly maxing out family cell phone plans. [57] In the spring of 2020, the school focused on mail-in homework options, and teachers worked through strategies to sustain student engagement at a distance. In the summer of 2020, Kimball Sekaquaptewa, technology director for the school, acquired and delivered hundreds of Google Chromebooks to students, yet unfortunately, our team is still hearing stories of parents driving their children to McDonald's parking lots to complete schoolwork for hours at a time, and how families are frustrated as they realize how limited the Chromebook is without a stable high-speed Internet connection. The potential for increasing educational and economic marginalization in our partner communities is substantial. Awareness of specific obstacles to deployment during a time of relative economic prosperity has helped us realize the need for community-based emergency Internet readiness planning, during which the usual work processes are slowed or suspended. Together, these also help us realize the need for indigenous network advancements through technologies engineered to place.

6 DISCUSSION & IMPLICATIONS FOR RURAL COMPUTING

We define rurality as the observable relational, economic, and geographic distance from urban centers. In our study, we find that rurality is simultaneously historically manufactured and self-organizing, as groups who reside in regions with low population densities shape institutions, infrastructures, and services to match their patterns of life. This definition allows us to structure insights gained from our work with one such infrastructure, the REDInet network of northern New Mexico, and its end-user communities. Understanding rurality as spatial and place-based with political, economic, and epistemic implications helps us discern the social textures of life shaping rural computing work processes, the measurement gap between federal datasets and local needs, and care as a resource and relational means for deploying networked systems.

6.1 Navigating Social Textures & Temporalities

Philosophers of justice characterize epistemic friction as the productive cognitive dissonance that occurs when an individual experiences a way of life significantly different from their own [31, 52]. The open-minded individual benefits from epistemic friction; their worldview expands, and they become adept at cross-cultural boundary-spanning. A narrow-minded individual fears the friction and refutes, denies or downplays social difference, which compounds ignorance and reproduces race/gender and class oppressions. [52]. The joint cooperative agreement that stabilizes REDInet is based on a productive epistemic friction in which the board members negotiate the needs of their constituent communities, some of which bear strongly Indigenous Puebloan worldviews, while others live by northern New Mexico Hispanic lifeways, and yet others tend toward American mainstream worldviews that value ICTs for capitalist commerce. Observing and being a part of different decision-making processes with different board members reveals the contours of epistemic friction shaping REDInet innovation as it occurs through each Pueblo, Rio Arriba County, and with regard for the politics of the state and the capitol city of Santa Fe. At times, board members reference histories in their communities, slipping into Indigenous languages and cultural references or Spanish and Chicano cultural references. Invisible due to its ubiquity is the powerful economic presence of the state's wealthier Anglo-American population, including their desires for a high-speed Internet that sustains a mainstream American set of lifeways alongside a distinctly New Mexican gentrified liberal multicultural tourism. The introduction of our team into the REDInet circle introduces yet another cultural set of norms: the practices of the fast-paced urban university computing lab. In general, in academia, we make decisions rapidly and deploy rapidly, as we are driven by funding timelines, project milestones, and annual publication cycles. As academics, our effort is measured by our productivity, whereas for our project partners, effort is often measured by stabilization of relationships, including service to their constituent communities and distinct governments, the end-users of REDInet.

Understanding the relational nature of the boundary-spanning work required to deploy ICTs in rural contexts reveals how rural computing relates to differences in discourses and pace of life. Our work reveals how pace of life is shaped by the workflows that are possible within tribal and county governments with limited personnel, as well as the cross-cultural code-switching that ICT champions undertake as they advance a decision process through layers of government. Our work also reveals the assumptions we carry into the project as university researchers driven by our own research agendas and goals, some of which are incongruous or irrelevant to the needs of our partner communities.

Perhaps this is most apparent in our efforts to provide digital skills training based on national digital literacy standards, which prior studies have indicated are an ill fit for Indian Country and people of color communities. Our team has had to develop an ear for expressions of Native

American digital literacies, which are largely focused on immediate family needs, Puebloan community interests around data sovereignty, privacy and protection of sacred knowledges, and uses of social media for community-organizing and Indigenous advocacy. Indeed, one of our project partners noted a telling insight by a tribal librarian who framed digital literacy training for her young patrons as an opportunity to reflect on how to apply computing skills not to assimilate into American culture, but rather on how "to be a better Native American." This finding reflects prior HCI work on distinctive digital literacies among rural and Indigenous peoples [7]. Native scientific concepts of place-based mathematics have also been useful, as they provide a frame for interpreting ICT champions decision processes as they calculate costs of local digital infrastructure plus potential for local investment with regard for ancestral systems of knowledge and governance. This kind of design thinking collocates system-level design questions with epistemic and moral questions about the right way to be in Puebloan homelands.

Implication for rural computing: In sum, researchers hailing from fast-paced product-driven university labs are well-advised to incorporate methods that account for the experience of epistemic friction in their design process and fieldwork. In this, our finding is similar to those of health informatics researchers who apply community-based design methods [81]. Prior work by researchers who apply participatory and community-based research approaches also express a similar appreciation for the pluriverse of worldviews that emerge through HCI design interventions [3, 66, 91]. To be clear, our work is revealing more than polyvocality in system design; it is revealing epistemic plurality shaped in part by various identity-based communities' ability to normatively craft everyday activities around a stable home Internet connection. It is revealing how urban and semi-urban gentrification in New Mexico contributes to Internet access and connectivity challenges among those with ancestral claims to land, territory, and belonging. We thus contribute to HCI work on gentrification and social justice that asks HCI researchers to develop methods that "reveal the layers and levels of accountability in gentrification processes," especially as these shape digital divides through rural and remote regions bordering Indian Country [18]. If a goal of rural computing is to enhance the distribution of relevant content through rural and urban data flows, than it is appropriate for researchers to likewise practice cross-cultural boundary-spanning work by broadening the epistemic capacity of personnel working in university labs and funding agencies, and who, due to lack of understanding of the social textures of rural and Indigenous ways of life privilege a hyper-connected urban pace of life, industry-centered design methods, and commerce-oriented values around Internet connectivity, access, and governance [39]. In this, we find ourselves in agreement with work by HCI researchers integrating a call to action around critical race theory, decolonization, and social justice in the field of HCI [30, 62, 72].

6.2 Accuracy & Accessibility of Federal Government Data

One of the critical steps in the Full-Circle Framework is evaluating existing technical infrastructure through the analysis of datasets about existing technical infrastructure. For PuebloConnect, strategizing new infrastructure required examining data about existing TVWS (Section 5.2.3) and mobile broadband infrastructure (Section 5.2.4). Through the collection of on-the-ground measurements in northern New Mexico, we found that federal data *overreported the availability of mobile broadband services* in rural tribal census blocks and *underreported the availability of usable TVWS spectrum* for the Santa Clara Pueblo. While the particular reasons for these discrepancies are difficult to discern, public records available about how these data are generated reveal several clues as to why discrepancies between on-the-ground measurements and federal data about infrastructure exist. Federal records about both mobile broadband coverage and TVWS spectrum availability are calculated using radio signal propagation models [10, 25]. One of the issues with these propagation models is that they rely exclusively on data and projections generated by incumbents and vendors

(TVWS) or mobile broadband ISPs (LTE) and do not integrate any data measured by potential consumers in reported services areas [10, 12, 36].

Implication for rural computing: Community-based and participatory HCI methods reveal the complexity of the problem space and the design space, and through the participatory process, help researchers and practitioner stakeholders alike to identify power inequities as well as generate in situ solutions. [39, 78, 81] Working with our partners through the Full-Circle Framework as we seek to extend middle-mile connectivity reveals how a lack of accurate federal information about existing telecommunications technology can disenfranchise rural and tribal communities, and can hamstring technical research, infrastructural development, and resource advocacy efforts in these communities. There is a need for research computing efforts to innovate rural ground-truthing practices as a matter of routine public infrastructure maintenance. If centered in community-based practices, these kinds of measurement campaigns could empower rural and tribal communities through the identification of usable spectrum resources and gaps in service areas. Digital divide researchers could also bolster quantitative evidence with the layers of policy research needed to shape governance actions. This is in the interest not only of rural and tribal communities, but also for state and federal government who seek to maximize the utility of natural spectrum and information resources. Moreover, these practices require synthesizing techniques from multiple disciplines that can dialog with each other to develop a more holistic perspective on the status of rural ICT infrastructure. This involves aggregation and integration of data collected through qualitative and quantitative methods: regular surveys of Internet access and availability; interviews with rural residents about Internet practices; citizen science efforts to measure and verify coverage areas; and federal and state sponsored efforts to verify spectrum availability models with strategic spectrum scanning efforts (such as those reported in Section 5.2.3). Critically, all of these measurement instruments and resulting information about the state of Internet infrastructure need to be made relevant to the rural communities that have been historically disenfranchised by federal data practices surrounding ICT infrastructure. We are thus in agreement with HCI researchers who "stress the potential role of HCI research for deepening understanding of...rural community change" [38, 45].

6.3 Care as a Critical Resource

The idea of care as a resource is integral to computer scientific adaptations of a feminist ethics of care. Well before the COVID-19 outbreak in the southwest US, we were conscientious that we were asking IT directors and network administrators to add extra tasks to their days work as they supported our research goals. We were also conscientious of the structural inequities that shape limited Internet access and marginalize anchor institutions in tribal and rural communities. Thus our process of identifying local professionals to interview and learn from, and creating digital skills programming has been entirely relational: built upon prior respected relationships that each of us already had due to our profession, friendships, kinship networks, and prior work. Though some practitioners of more methodologically conservative approaches to scientific orthodoxy denigrate so-called "snowball sampling," the fields of HCI and CSCW value innovative and unconventional approaches to participatory methods, including convenience sampling and expert participant pools. Alternatively, at a paradigmatic level, Native science values the trustworthiness and truth value of relational engagement. Indeed, the deeply reflexive and transformative expectations of both Native science and feminist approaches can in some cases collapse the relational distance between the researcher and the researched. We become attached and attuned to anticipate the needs of our research partners, communities, and sites as places of responsiveness and responsiblity. When each of us received news of the outbreak in the region, we naturally empathized. We recalled what Raymond Ortiz shared about the implications of an at-risk student missing 3 days of homework due to a power outage. It is now apparent that our partner communities are experiencing the economic and social impacts of COVID-19 in markedly more challenging ways than wealthier, non-tribal, urban, hyper-connected communities. By the end of March, our team doubled our efforts to deploy TVWS base stations quickly to the region, began documenting which communities might benefit from a New Mexico state Google Chromebook program for students, began working with a physician out of Northern Navajo Medical Center to raise awareness of regional outbreaks and craft letters to the governor about the need for Internet infrastructure toward patient care, and began layering crowdsourced cellular mobility data and publicly-accessible epidemiological data to identify regions most in need of health resources in northern New Mexico.

Implication for rural computing: We can measure care as a resource because when it is present in a project, the project team rapidly and compassionately adapts and responds to unexpected circumstances. There is greater courage in delivering challenging news and pursuing unexpected work-arounds, which is what we did when we discovered limited available spectrum channels, and realized that our project partners were working overtime as essential workers. We have found ways to make our work relevant to the needs of the community. This kind of sensitivity is due to not only our practice of relational engagement, but also due to a digital ethnography that keenly discerns the multivalent relationships and institutional power structures shaping rural deployment and innovation. Most challenging for us is the fact that we are continuing our efforts though as women professionals we also shoulder the unexpected labor of care in the home and in our workplaces. We now assess our capacity for labor on a weekly basis, and constantly share information as it emerges rapidly in the field. If we revisit the ABCD model of ICT deployment, the COVID-19 pandemic certainly indicates the value of care as an asset in community technology deployment.

The so-called “infodemic” shaping COVID-19 response has major implications for rural computing, as nearly every technically skilled personnel serving a rural community finds herself called upon to support community and family Internet access and connectivity needs in addition to deciphering the information integrity of news about the pandemic and its local impact. As a team, we are all working double duty, and look forward to a healthier future when we can join efforts to more equitably distribute the labor of science, technical innovation, and rapid emergency technical response so that our partner communities and others like them are not mired in yet another layer of the digital public health divide. Fundamentally, rural deployment of innovative computing is hampered unless we can convince the FCC to invest in and provide more accurate and methodologically transparent datasets. Additionally, our experience is indicating the need for a priority for rural and tribal communities in addition to a simplified process to grant access to emergency spectrum licensing in service to their communities during months of shelter-in-place requirements. We join New Mexico technologists and others in Indian Country who very recently helped craft the Digital Reservations Act, introduced by Laguna Pueblo member and New Mexico Democratic Representative Deb Haaland and Massachusetts Democratic Representative Elizabeth Warren. While it is still being read in the House and Senate, we encourage rural computing researchers, digital divide researchers, and digital literacy researchers to carefully analyze the processes and activities outlined in the act with regard to the specific communities we work to empower. If passed, HCI researchers can play a key role in contributing participatory and community-based projects around infrastructural innovation, technical capacity-building, alternative digital futures and strategic planning, distance education, health informatics, and removal of structural barriers that impede rural community command of middle-mile and last-mile Internet infrastructures.

While not all changes in a research context are as a dramatic as a global pandemic, disruption and dynamism is to be expected in the rurality we have described in this article. Thus, a lesson that others in the rural computing research community can draw from our experience is the need to measure researcher and community capacity for care relative to the ambitiousness of the project outcomes and the complexity of the rural landscape. It is our intention that the Full-Circle Framework can provide researchers with a way to systematically and effectively direct resources among synergistic research phases as a way to effectively navigate the dynamic challenges surrounding sociotechnical projects in rural tribal contexts *while continuing to progress towards long-term community sovereignty goals*. Like farmers who must rapidly shift techniques and tactics to help a squash plant flourish through drought, storm, pest, and soil depletion, researchers need to be able to work with agility to support the organic existence of computing projects in rural communities. The agility required to respond appropriately requires researchers to possess significant care for the long-term project outcomes (both for rural communities and the research community), the community at-large and specific community collaborators, funding resources, and individual members of the research team.

7 CONCLUSION

A significant contribution of the Full-Circle Framework is its holistic and place-based comprehension of computing research, from the physical to the social, political, geographic, cultural, and its layering of relationships and ways of knowing over complex processes of novel technical system deployment. It is a framework that allows computing researchers to work in rural contexts such that the resources that they bring into a community can be directed by the community to work synergistically across a dynamic and organic environment to empower community sovereignty over a long-term timescale. While our research context takes place in the unique context of tribal communities, the Full-Circle Framework and lessons learned are relevant to any computing research projects that aim to strengthen and grow community sovereignty. A common failure of many ICTD projects occurs through the limited qualitative engagement that designers have with their partner communities. There is often a presumption of understanding about what life is like in locations far away and far removed from the well-connected fast-paced life of the university computing lab. Yet if designers developed a more humanistic–not to be confused with human-centered-approach to digital ethnography, then they might allow themselves to benefit from the epistemic friction needed to truly innovate for a place and a people over time. The learning they encounter in the field might then embolden them to turn the powerful influence of scientists and industry researchers to advocate for equitable computing across many domains.

Through the PuebloConnect project, our team has deepened in our knowledge of Indian Country and the unique histories of place in northern New Mexico. We are becoming keenly aware of the nature of structural and skill-based obstacles impeding innovation in rural settings, especially as these interface with cultural difference and histories of economic disenfranchisement. In the midst of the so-called “infodemic” we recognize how rural communities are hampered by the lack of information integrity in federal datasets indicating Internet coverage and spectrum availability. In sum, while we can read these findings against the digital divide literature and the ICTD literature, we are finding that we prefer a more nuanced language to articulate the covalent relationship between innovative design and disenfranchisement, and between skill and capacity. Throughout, the function and role of political will remains elusive: if the state does not either subsidize or provide these complex infrastructures to their residents, than what does that indicate about the capacity of the state to provide for basic human rights and civil liberties, including public education, employment opportunities, and the means to innovate and form productive enterprise? Though beyond the scope of our investigation at this point, these kinds of questions stimulate our thinking together as we try to move beyond bridging the imagined “haves” and “have-nots” and instead focus on innovating appropriate systems for communities who can then redefine what connectivity means for them.

REFERENCES

[1] Syed Mustafa Ali. 2017. Decolonizing information narratives: Entangled apocalyptics, algorithmic racism, and myths of history. *Proceedings of the International Society for Information Studies* 1, 3 (2017), 50.

[2] Rural Wireless Association. 2019. Mobile Wireless in Vermont. Retrieved from https://publicservice.vermont.gov/sites/dps/files/documents/Connectivity/BroadbandReports/2019/Mobile Wireless Report.pdf.

[3] Caldwell Ben, Bar Francois, Stokes Benjamin, and Baumann Karl. 2018. Participatory design fiction: Community storytelling for speculative urban technologies. In *Proceedings of the CHI Extended Abstracts*.

[4] M. Berlingerio, M. Coscia, F. Giannotti, A. Monreale, and D. Pedreschi. 2011. Foundations of multidimensional network analysis. In *Proceedings of the International Conference on Advances in Social Networks Analysis and Mining*. Kaohsiung, Taiwan, 485–489.

[5] Brittany Bernstein. 2017. Santa Clara librarian tradition-like role. Rio Grande Sun (2017). Retrieved from http://www.riograndesun.com/news/santa-clara-librarian-tradition-like-role/article_638e86c0-5cdb-11e7-ac04-2b9eb5f59c32.html.

[6] Bruce Bernstein and Scott Ortman. 2020. From collaboration to partnership at Pojuaque, New Mexico. *Advances in Archaeological Practice* 8, 2 (2020), 1–16.

[7] Hardy Dianna and Bidwell Nicola. 2009. Dilemmas in situating participation in rural ways of saying. In *Proceedings of the 21st Annual Conference of the Australian Human-Computer Interaction Special Interest Group on Design*.

[8] Darrah Blackwater. 2019. Time for the 'well-meaning man' to return spectrum rights to tribes. Retrieved from https://newsmaven.io/indiancountrytoday/opinion/time-for-the-well-meaning-man-to-return-spectrum-rights-to-native-american-tribes-zwBl13XNX0y4P0kAsw5IlA. *Indian Country Today* (November 2019).

[9] Karl Bode. 2019. Microsoft Says the FCC 'Overstates' Broadband Availability in the US. Retrieved from https://www.vice.com/en_us/article/pan48b/microsoft-says-the-fcc-overstates-broadband-availability-in-the-us.

[10] Alistair Braden. 2018. Long Read: Enabling TVWS & protecting incumbents. Retrieved from https://www.nominet.uk/long-read-enabling-tvws-protecting-incumbents/.

[11] Jon Brodkin. 2019. Windstream, ISP with 1 million customers, files for bankruptcy. *Ars Technica* (2019).

[12] Jon Brodkin. 2020. AT&T gave FCC false broadband-coverage data in parts of 20 states. Retrieved from https://arstechnica.com/tech-policy/2020/04/att-gave-fcc-false-broadband-coverage-data-in-parts-of-20-states/.

[13] Ronald Brown, David J. Barram, and Larry Irving. 1995. Falling through the Net: A survey of 'have nots' in rural and urban America. Retrieved from https://www.ntia.doc.gov/ntiahome/fallingthru.html.

[14] Wendy Brown. 2019. Windstream asks federal bankruptcy court to extend Chapter 11 protection until late 2020. *Talk Business and Politics* (2019).

[15] Simone Browne. 2015. *Dark Matters: On the Surveillance of Blackness*. Duke University Press.

[16] Ingrid Burrington. 2016. *Networks of New York: An Illustrated Field Guide to Urban Internet Infrastructure*. Melville House.

[17] Ranveer Chandra and Thomas Moscibroda. 2019. Perspective: White space networking with Wi-Fi like connectivity. *ACM SIGCOMM Computer Communication Review* 49, 5 (2019), 107–109.

[18] Loukissas Yanni and Corbett Eric. 2019. Engaging gentrification as a social justice issue in HCI. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*.

[19] Myron Dewey. 2017. Lecture and Screening of Awake: A Dream from Standing Rock. November 13, 2017, Tempe, Arizona.

[20] Leslie Dodson, Ravi Sterling, and John Bennett. 2012. Considering failure: Eight years of ITID research. In *Proceedings of the 5th International Conference on Information and Communication Technologies and Development*.

[21] Marisa Elena Duarte. 2017. *Network Sovereignty: Building the Internet across Indian Country*. University of Washington Press.

[22] Jacob Dubé. 2017. Oil Lobbyists: Thunderbird strike video game 'promotes ecoterrorism'. *VICE* (2017). Retrieved from https://www.vice.com/en_us/article/xwawq3/oil-lobbyists-thunderbird-strike-videogame-promotes-ecoterrorism.

[23] John Eggerton. 2019. Dems Seek FCC Explanation of Faulty Broadband Coverage Data. Retrieved from https://www.broadcastingcable.com/news/dems-seek-fcc-explanation-of-faulty-broadband-coverage-data.

[24] Federal Communications Commission. 2019. Broadband Deployment Report. Retrieved from https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2019-broadband-deployment-report.

[25] Federal Communications Commission. 2019. Measuring mobile broadband performance. Retrieved from https://www.fcc.gov/general/measuring-mobile-broadband-performance.

[26] Federal Communications Commission. 2020. FCC Acts to Support Connectivity on Tribal Reservation in New Mexico. Retrieved from https://www.fcc.gov/document/fcc-acts-support-connectivity-tribal-reservation-new-mexico.

[27] Federal Communications Commission. 2020. White Space. Retrieved from https://www.fcc.gov/general/white-space.

[28] First Nations Information Governance Centre. 2020. The First Nations Principles of OCAP. Retrieved from https://fnigc.ca/ocap.

[29] Olivia Fleming. 2015. Could a 168 dollar bracelet revive the Native American economy? *Elle* (2015). Retrieved from https://www.elle.com/fashion/accessories/a29238/new-luxury-jewelry-label-thats-investing-in-women/.

[30] Dimond Jill, Irani Lilly, Hirsch Tad, Muller Micheal, Bardzell Shaowen, and Fox Sarah. 2017. Social justice and design: Power and collaboration in oppressive systems. In *Proceedings of the Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*.

[31] Miranda Fricker. 2007. *Epistemic Injustice: Power and the Ethics of Knowing*. Oxford University Press.

[32] Eric Gilbert, Karrie Karahalios, and Christian Sandvig. 2008. The network in the garden: An empirical analysis of social media in rural life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'08)*. Association for Computing Machinery, Florence, Italy, 1603–1612. DOI: https://doi.org/10.1145/1357054.1357304

[33] Mark Goldstein. 2006. *Telecommunications: Challenges to Assessing and Improving Telecommunications for Native Americans on Tribal Lands*. Government Accounting Office.

[34] Mark Goldstein. 2016. *Tribal Internet Access: Increased Federal Coordination and Federal Performance Measurement Needed*. Government Accounting Office.

[35] Mark Goldstein. 2018. *Broadband Internet: FCC's Data Overstate Access on Tribal Lands*. Government Accounting Office.

[36] Government Accountability Office. 2018. Broadband Internet: FCC's Data Overstate Access on Tribal Lands.

[37] Jean Hardy, Chanda Phelan, Morgan Vigil-Hayes, Norman Makoto Su, Susan Wyche, and Phoebe Sengers. 2019. Designing from the rural. *Interactions* 26, 4 (2019), 37–41.

[38] Jean Hardy, Susan Wyche, and Tiffany Veinot. 2019. Rural HCI research: Definitions, distinctions, methods, and opportunities. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (Nov. 2019), 33 pages. DOI: https://doi.org/10.1145/3359298

[39] Christina Harrington, Sheena Erete, and Anne Marie Piper. 2019. Deconstructing community-based collaborative design: Towards more equitable participatory design engagements. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (Nov. 2019), 1–25. DOI: https://doi.org/10.1145/3359318

[40] Ellen Johanna Helsper. 2012. A corresponding fields model for the links between social and digital exclusion. *Communication Theory* 22, 4 (10 2012), 403–426. DOI: https://doi.org/10.1111/j.1468-2885.2012.01416.x

[41] David L. Johnson, Elizabeth M. Belding, and Gertjan Van Stam. 2012. Network traffic locality in a rural African village. In *Proceedings of the 5th International Conference on Information and Communication Technologies and Development*. 268–277.

[42] Miriam Jorgensen. 2012. *Sustaining Indigenous Culture: The Structure, Activities, and Needs of Tribal Archives, Libraries, and Museums*. Association of Tribal Libraries, Archives, and Museums.

[43] Miriam Jorgensen, Traci Morris, and Susan Feller. 2014. *Digital Inclusion in Native Communities: The Role of Tribal Libraries*. Association of Tribal Archives, Librarians, and Museums.

[44] Naveena Karusala, Aditya Vishwanath, Arkadeep Kumar, Aman Mangal, and Neha Kumar. 2017. Care as a resource in underserved learning environments. *Proceedings of the ACM on Human Computer Interaction* 1, CSCW (Dec. 2017), 22 pages. DOI: https://doi.org/10.1145/3134739

[45] Ronald Kline. 2000. *Consumers in the Country: Technology and Social Change in Rural America*. Hopkins University Press.

[46] Kretzman and McKnight. 1993. *Building Communities from the Inside Out*. ACTA Publications

[47] Elizabeth LaPensee. 2020. When rivers were trails: Cultural expression in an indigenous video game. *International Journal of Heritage Studies* 27, 3 (2020), 281–295. DOI: https://doi.org/10.1080/13527258.2020.1746919

[48] T. S. Last. 2019. Española internet service is also 'low and slow'. *Albuquerque Journal* (2019). Retrieved from https://www.abqjournal.com/1391675/espanola-internet-service-is-also-low-and-slow.html.

[49] Charlotte P. Lee, Paul Dourish, and Gloria Mark. 2006. The human infrastructure of cyberinfrastructure. In *Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work (CSCW'06)*. Association for Computing Machinery, New York, NY, 483–492. DOI: https://doi.org/10.1145/1180875.1180950

[50] Cunningham Gord and Mathie Allison. 2002. From clients to citizens: Asset-based community development as a strategy for community-driven development. *Development in Practice* 13, 5 (2002), 474–486.

[51] Shannon Mattern. 2017. *Code and Clay, Data and Dirt: Five Thousand Years of Urban Media*. University of Minnesota Press.

[52] Jose Medina. 2013. *The Epistemology of Resistance: Gender and Racial Oppression, Epistemic Injustice, and the Social Imagination*. Oxford University Press.

[53] Katherine Meloche. 2017. Playing in the Digital Qargi: Inupiat Gaming and Isuma in Kisima Innitchuna. *Transmotion* 3, 4 (2017), 1–21.

[54] Amanda Meng, Carl DiSalvo, and Ellen Zegura. 2019. Collaborative data work towards a caring democracy. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–23.
[55] Raymond Michalowski and Jill Dubisch. 2001. *Run for the Wall: Remembering Vietnam on a Motorcycle Pilgrimage*. Rutgers University Press.
[56] C. Mikeka, M. Thodi, J. S. P. Mlatho, J. Pinifolo, D. Kondwani, L. Momba, M. Zennaro, and A. Moret. 2014. Malawi television white spaces (TVWS) pilot network performance analysis. *Journal of Wireless Networking and Communications* 4, 1 (2014), 26–32.
[57] Elizabeth Miller. 2020. Santa Fe Indian school pivots to offline learning to ensure access during COVID-19 pandemic. New Mexico In *Depth*. https://nmindepth.com/2020/05/02/santa-fe-indian-school-pivots-from-digital-to-offline-learning-to-ensure-access-during-covid-19-pandemic/.
[58] National Science Foundation. 2018. SCC: PuebloConnect: Expanding Internet Access and Content Relevance in Tribal Communities. Retrieved from https://www.nsf.gov/awardsearch/showAward?AWD_ID=1831698&HistoricalAwards=false.
[59] Kagiso Ndlovu, Zablon A. Mbero, Carrie L. Kovarik, and Arif Patel. 2017. Network performance analysis of the television white space (TVWS) connectivity for telemedicine: A case for Botswana. In *Proceedings of the 2017 IEEE AFRICON*. IEEE, 542–547.
[60] Michael Nekrasov, Vivek Ardash, Udit Paul, Esther Showalter, Morgan Vigil-Hayes, Ellen Zegura, and Elizabeth Belding. 2019. Evaluating LTE coverage and quality from an unmanned aircraft system. In *Proceedings of the 16th IEEE Conference on Mobile and Ad-hoc and Smart Systems*. Monterrey, CA.
[61] Safiya Noble. 2018. *Algorithms of Oppression: How Search Engines Reinforce Racism*. NYU Press.
[62] Smith Angela, To Alexandra, Toyama Kentaro, and Ogbonnaya-Ogburu Ihudiya Finda. 2020. Critical race theory for HCI. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*.
[63] Nicholet Deschine Parkhurst. 2017. Protecting oak flat: Narratives of survivance as observed through digital activism. *Australasian Journal of Information Systems* 21 (2017), 1–17.
[64] Nicholet Deschine Parkhurst, Traci Morris, Emory Tahy, and Karen Mossberger. 2015. The digital reality: e-government and access to technology and internet for American Indian and Alaska Native populations. In *Proceedings of the 16th Annual International Conference on Digital Government Research*. 217–229.
[65] Anibal Quijano. 2000. Coloniality of power, Eurocentrism, and Latin America. *Nepantla: Views from the South* 1, 3 (2000), 533–580.
[66] Rose Emma, Kolko Beth, and Racadio Robert. 2014. Research at the margin: Participatory design and community-based participatory research. In *Proceedings of the 13th Participatory Design Conference*.
[67] Matt Rantanen. 2020. Business models for community networks. In *Proceedings of the Indigenous Connectivity Summit 2020*.
[68] Rural Wireless Association. 2018. RWA Calls for FCC Investigation of T-Mobile Coverage Data. Retrieved from https://ruralwireless.org/rwa-calls-for-fcc-investigation-of-t-mobile-coverage-data/.
[69] Christian Sandvig. 2012. *Connection at Ewiiaapaayp Mountain*. Routledge, New York, NY.
[70] Anita Say Chan. 2014. *Networking Peripheries: Technological Futures and the Myth of Digital Universalism*. MIT Press.
[71] Anique Scheerder, Alexander van Deursen, and Jan van Dijk. 2017. Determinants of Internet skills, uses and outcomes. A systematic review of the second-and third-level digital divide. *Telematics and Informatics* 34, 8 (2017), 1607–1624.
[72] Heike-Winschiers Theophilus, Loi-Daria, Kambunga Asnath Paula, Samuel Marley Muudeni, de Paula Rogerio, and Smith Rachel. 2020. Decolonising participatory design practices: Towards participation otherwise. In *Proceedings of the 16th Participatory Design Conference*.
[73] Linda Tuhiwai Smith. 2013. *Decolonizing Methodologies: Research and Indigenous Peoples*. Zed Books Ltd.
[74] Linda Tuhiwai Smith. 2020. *Decolonizing Methodologies: Research and Indigenous Peoples*. Zed Books.
[75] Ramesh Srinivasan. 2019. *Beyond the Valley: How Innovators around the World are Overcoming Inequality and Creating the Technologies of Tomorrow*. MIT Press.
[76] Peter Stenberg. 2018. The purchase of Internet subscriptions in Native American households. *Telecommunications Policy* 42, 1 (2018), 51–60.
[77] Michael J. Stern, Alison E. Adams, and Shaun Elsasser. 2009. Digital inequality and place: The effects of technological diffusion on Internet proficiency and usage across rural, suburban, and urban counties. *Sociological Inquiry* 79, 4 (2009), 391–417.
[78] G. Susman. 1983. Action research: A sociotechnical systems perspective. In *Beyond Method: Strategies for Social Research*, G. Morgan (Ed.). Sage, Newbury Park, 95–113.
[79] Kentaro Toyama. 2015. *Geek Heresy: Rescuing Social Change from the Cult of Technology*. PublicAffairs.
[80] Tom Udall. 2012. Udall: Almost 8,000 in rural New Mexico to get high-speed Internet access. [Press release] July 26, 2012.

[81] Schaefbauer-Chris, Campbell Terrance, Senteio Charles, Siek Katie, Bakken Suzanne, Veinot Tiffany, and Unertl Kim. 2015. Integrating community-based participatory research and informatics approaches to improve the engagement and health of underserved populations. *Journal of the American Medical Informatics Association* 23, 1 (2015), 60–73.

[82] Alexander J. A. M. Van Deursen, Ellen J. Helsper, and Rebecca Eynon. 2016. Development and validation of the Internet skills scale (ISS). *Information, Communication & Society* 19, 6 (2016), 804–823.

[83] Jan A. G. M. Van Dijk. 2005. *The Deepening Divide: Inequality in the Information Society*. Sage Publications.

[84] Morgan Vigil, Elizabeth Belding, and Matthew Rantanen. 2016. Repurposing FM: Radio nowhere to OSNs everywhere. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work and Social Computing (CSCW'16)*. Association for Computing Machinery, San Francisco, California, 1260–1272. DOI: https://doi.org/10.1145/2818048.2820001

[85] Morgan Vigil, Matthew Rantanen, and Elizabeth Belding. 2015. A first look at tribal web traffic. In *Proceedings of the 24th International Conference on World Wide Web (WWW'15)*. International World Wide Web Conferences Steering Committee, Florence, Italy, 1155–1165. DOI: https://doi.org/10.1145/2736277.2741645

[86] Morgan Vigil-Hayes, Marisa Duarte, Nicholet Deschine Parkhurst, and Elizabeth Belding. 2017. #Indigenous: Tracking the connective actions of Native American advocates on Twitter. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW'17)*. Association for Computing Machinery, Portland, Oregon, 1387–1399.

[87] Morgan Vigil-Hayes, Nicholet Deschine Parkhurst, and Marisa Duarte. 2019. Complex, contemporary, and unconventional: Characterizing the tweets of the #NativeVote movement and Native American candidates through the 2018 US midterm elections. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–27.

[88] Gerald Vizenor. 1993. *Manifest Manners: Postindian Warriors of Survivance*. Wesleyan University Press.

[89] Kwok-Kee Wei, Hock-Hai Teo, Hock Chuan Chan, and Bernard C. Y. Tan. 2011. Conceptualizing and testing a social cognitive model of the digital divide. *Information Systems Research* 22, 1 (2011), 170–187.

[90] Shawn Wilson. 2009. *Research as Ceremony: Indigenous Research Methods*. Fernwood Publishing.

[91] Woodrow Winchester. 2018. Afrofuturism, inclusion, and the design imagination. *Interactions* 25, 2 (2018), 41–45.

[92] James C. Witte and Susan E. Mannon. 2010. *The Internet and Social Inequalities*. Routledge.

[93] Alexandra Witze. 2020. How the fight over a Hawaii mega-telescope could change astronomy. *Nature* (2020). Retrieved from https://www.nature.com/articles/d41586-020-00076-7.

[94] Lee-Morgan Jenny Bol Jun, De Santolo Jason, Smith Linda Tuhiwai, and Xiiem Joanne Archibald Q'um Q'um. 2019. *Decolonizing Research: Indigenous Storywork as Methodology*. University of British Columbia Press.

[95] E. Zegura, R. Grinter, E. Belding, and K. Nahrstedt. 2007. A rural lens on a research agenda for intelligent infrastructure. [white paper]. *Computing Community Consortium*. 1–6.

Received May 2020; revised January 2021; accepted March 2021