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Science for Some: Understanding Rural Leadership Intentions  for Minoritized Students' Access to Science



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By

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# Abstract

Science for Some: Understanding Rural Leadership Intentions for Minoritized Students' Access to Science

by

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Despite California's adoption of the Next Generation Science Standards in 2013, equitable science education remains largely unrealized for the 1 in 7 students who learn in rural settings. This qualitative, role-based case study examined the systemic and cultural/historical barriers that rural educational leaders encounter in increasing science education access for minoritized students, and the navigational strategies those leaders developed in response. Guided by Ray's (2019) Theory of Racialized Organizations, Young and Arnold's (2020) Emerging Framework for Inclusive Educational Leadership, and Ladson-Billings' (1995) Culturally Relevant Pedagogy, this study drew on semi-structured interviews with eleven rural California science education leaders across three tiers of rurality, from California's most isolated Tier 1 counties to statewide organizations. Findings revealed that barriers to equitable rural science education were structural, persistent, and compounding, rooted in accountability systems that deprioritized science, funding mechanisms that withheld professional learning resources, economies of scale that undermined instructional continuity, limited educator cultural competence, colonial and political histories, and social class divides that shaped which students were afforded access to rigorous science instruction. Indigenous students emerged as among the most consistently marginalized populations, a finding insufficiently addressed in the existing literature. Against these conditions, rural science education leaders navigated through place-based science leadership, sustained community partnerships, and equity-oriented professional learning redesign, which are all strategies that were powerful but structurally insufficient alone to produce systemic change. The study concludes with recommendations across research, policy, and practice that call for structural transformation, including dashboard accountability reform, expanded science professional learning funding, and institutionalized place-conscious science education which are changes commensurate with what the most marginalized students in rural California have long deserved.

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# Acknowledgements

Like the trees of rural California, I did not grow alone. For my mother, who gave so I could become, and for my family, whose roots held so I could finish.

# Chapter One: Science — An Academic Canary in the Education Coal Mines

The story of science education in the United States is indicative of where we are in the story of democracy itself. Geopolitical pressures of the Cold War brought science and technology into sharp national focus, catalyzing a broader public reckoning with what it meant to be a scientifically literate society. Rutherford and Ahlgren's (1989) landmark publication, *Science for All Americans*, issued through the American Association for the Advancement of Science (AAAS), gave shape to that reckoning by defining scientific literacy as the ability to understand the interdependence of science, mathematics, and technology, and to use scientific knowledge and ways of thinking for both personal and social purposes. Scientific literacy, the authors argued, was not merely an academic goal but a cornerstone of democratic participation — a means by which citizens could make informed decisions that extended well beyond conventional public understanding.

Building on this foundation, the Carnegie Corporation of New York and the National Academies convened a committee of eighteen science education experts whose work culminated in *A Framework for K–12 Science Education* (National Research Council [NRC], 2012)). The Framework called for common, high-quality science standards and acknowledged the multiple layers of interpretation that would be required to translate conceptual goals into classroom practice. Critically, among its thirteen recommendations, the Framework urged that issues of diversity and equity be centered in the design of standards, calling for performance expectations that offer students multiple ways of demonstrating science. California responded by adopting the Next Generation Science Standards (CA-NGSS) in 2013, a transition that represented a fundamental shift from rote knowledge acquisition toward three-dimensional learning, coherence, and local relevance (California Department of Education [CDE], 2016; CDE, 2023).

## Statement of the Problem

Yet more than a decade after NGSS adoption, the promise of equitable scientific literacy remains largely unrealized. Since adoption, education leaders have grappled with how to support teachers to be instructionally successful and students to be academically successful in science education (Allensworth et al., 2022; Anderson et al., 2018). The challenges of implementation are many and interconnected: the cultural mismatch between a predominantly white teaching workforce and an increasingly diverse student population, the inherently political nature of science education, and the complex instructional core linking students, teachers, and content (City et al., 2009; Hammond, 2015; Ladson-Billings, 1995). These challenges are further compounded in rural contexts, where 1 in 7 students learn in conditions defined by geographic isolation, resource scarcity, educator overwork, and persistent staffing instability (Showalter et al., 2023). Challenges of implementing NGSS persist, particularly in high-needs rural contexts where both affordances and constraints shape science instruction (Zinger et al., 2020). Rural educational leaders, already stretched across overlapping roles and responsibilities, are left to navigate deep systemic inequities with limited support, inequities that fall disproportionately on historically marginalized students.

It is within this landscape, and also from within this lived experience, that this study is situated. This study is guided by two sub-questions that together illuminate the problem from both a leadership and a systemic perspective:

*RQ1: What systemic barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?*

*RQ2: How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?*

Taken together, these questions lead to the central inquiry of this study: *What systemic and cultural/historical barriers do rural education leaders encounter and navigate in increasing access to science education for minoritized students?*

**Overview of Research Design**

This study employs a semi-structured ethnographic methodology to examine the experiences of rural educational leaders navigating science education for minoritized students. The qualitative, semi-structured interviews were well suited to this inquiry because they centered the lived experiences, perspectives, and contextual knowledge of participants, allowing patterns of systemic and cultural barriers to emerge organically from the data rather than being imposed by the researcher.

Eleven participants *(N = 11)* were selected through a two-part purposeful selection process designed to ensure both geographic and contextual relevance to the study's focus on rural science education leadership.

The first criterion was location. Participants were drawn from the California Rural Task Force, a designation comprising 26 California counties with populations under 250,000. This population and geographic boundary ensured that all participants operated within contexts defined by the isolation, resource constraints, and community dynamics characteristic of rural educational settings.

The second criterion was priority, which was established through a crosswalk with data from the Public Policy Institute of California (PPIC). Specifically, PPIC infrastructure needs data was verified against California Rural Task Force county designations to identify which rural populations, of California's 26 rural counties, could most reliably be characterized as the most rural. Counties where infrastructure deficits and rural task force criteria converged were prioritized, ensuring that participants represented the communities where the compounding effects of rurality and educational need were most pronounced and most central to the study's inquiry.

Finally, participants were required to meet a functional job survey threshold, demonstrating that they performed at least three of the following five leadership functions within their role:

- Provides professional learning to science educators
- Disseminates California Department of Education and State Board of Education guidance to local educational agencies (LEAs)
- Elevates the contextualized needs of LEAs to the CDE and State Board
- Plans and implements science-related activities
- Advocates for the need for public science education

This prequalification criterion reflects the well-documented reality that rural educational leaders routinely occupy overlapping roles and responsibilities (Copeland, 2013), and ensures that participants bring a multidimensional understanding of the systems they navigate on behalf of minoritized students.

Data collection consisted of 45-to 60-minute semi-structured interviews conducted online, allowing for geographic flexibility across rural settings while maintaining the depth of conversation necessary for ethnographic inquiry. Participants completed a consent process prior to their interview, and email follow-up was used as needed to clarify or extend responses. Data analysis focused on identifying patterns, tensions, and themes across participant accounts, with particular attention to the systemic and cultural barriers surfaced through their narratives.

**Rationale and Significance**

Understanding what is happening to minoritized students in rural science education is not a peripheral concern; it is a matter of national importance. Rural educational settings are far from rare; they constitute the learning environment for 1 in 7 students across the United States (Showalter et al., 2023), making rurality one of the most common yet least examined contexts in education research. When the experiences of students in these settings are overlooked, the gaps in both knowledge and opportunity compound quietly and persistently across generations.

At the same time, the United States faces an urgent and well-documented need for STEM innovation as a driver of national advancement. Science, technology, engineering, and mathematics are the foundations upon which economic competitiveness, public health, environmental sustainability, and democratic decision-making rest. A nation that fails to cultivate scientific literacy among all of its students, particularly those in rural and historically marginalized communities, is a nation that narrows its own capacity for innovation and progress.

The significance of this study lies at the intersection of these two realities. By examining how rural educational leaders navigate the systemic and cultural barriers that disenfranchise minoritized students from science education, this research contributes to a more complete understanding of what equitable STEM access requires in practice, across all contexts. The findings have implications not only for rural California but for any context in which the promise of science education has yet to reach the students who need it most.

**Researcher Positionality**

My curiosity about science education is deeply personal. Growing up as a Black woman in the rural Central Valley of California, I experienced science education first as a student, then as a teacher, later as a county administrator, and as an instructor for integrated math and science courses in the teacher preparation program at UC Merced. Currently, as a science steering team member for a statewide initiative, I continue to wonder what is happening with minoritized students studying science in rural locations. School site after school site, year after year, I have wondered why minoritized students — many of whom are immersed in nature — remain unable to attain proficiency in science. It doesn't make sense, and so I began to investigate.

To verify that my childhood experiences and professional observations were accurate, I revisited the California Department of Education data for 2023 and confirmed that a staggering 69.82% of California students assessed in science were found to be below satisfactory levels (CDE, 2023). A future with roughly three of every ten California students being adequately prepared for science is a problem, as science, at its core, is the process of deep observation that has the potential to support students to "answer their own authentic questions and solve real-world problems that are important to them" (National Academies of Sciences, Engineering, and Medicine [NASEM], 2022, p. vii)). Despite the promise of science education to center student experiences through observation, education itself "has played a key role in perpetuating unequal social structures and maintaining power for elite members of society" (NASEM, 2024, pp. 2–3).

As a Black female statewide science education leader, I challenge notions of neutral purposes and practices of science (NASEM, 2024). Black, Indigenous, and People of Color (BIPOC) have been subjugated by the dominant group in much the same way that nature has been; exploitation of people occurs to maintain hierarchies of power (Wilkerson, 2020). Centering the voices and experiences of children who are too often treated as "social becomings" rather than "social beings" (Wall, 2022), my research process consists of collaborative inquiry, encouragement of political participation, questioning of methods, and highlighting of issues and concerns that persist for minoritized students in rural science education.

**Key Terminology**

The following terms are used throughout this study and are defined here to establish a shared understanding of the conceptual language that frames this work.

*California Department of Education (CDE)* is the state agency responsible for overseeing public education in California, including the adoption and implementation of academic standards, curriculum frameworks, and accountability systems. The CDE serves as the primary conduit between state education policy and local educational agencies across California (CDE, 2023).

*Cultural Responsiveness* is an educational approach that actively recognizes, respects, and integrates students' cultural backgrounds into teaching and learning practices, fostering academic success, cultural competence, and sociopolitical consciousness (Ladson-Billings, 1995; Hammond, 2015).

*Culture* refers to the shared values, beliefs, norms, customs, language, and ways of knowing that shape how individuals experience, interpret, and engage with the world. Culture is both dynamic and deeply rooted in community and identity (Gay, 2002).

*Culturally Relevant Pedagogy* is a foundational framework for equitable teaching that centers students' cultural identities, lived experiences, and community knowledge as essential resources for academic learning. Developed by Ladson-Billings (1995), it rests on three interdependent tenets — student learning, cultural competence, and critical consciousness — positioning education not merely as the transmission of dominant knowledge but as a vehicle for affirming who students are, developing their capacity to navigate multiple cultural contexts, and cultivating their ability to identify and challenge the societal conditions that produce inequality.

*Culturally Sustaining Pedagogy* extends culturally responsive teaching by not only recognizing and incorporating students' cultural backgrounds but actively working to sustain and revitalize the linguistic, cultural, and community practices of historically marginalized students. Rather than treating culture as a bridge to dominant academic norms, culturally sustaining pedagogy positions the dynamic cultural practices of communities of color as worthy of preservation in their own right (Paris & Alim, 2014).

*Local Educational Agency (LEA)* refers to a public school district, county office of education, or other public authority responsible for the administration of public elementary and secondary schools within a defined geographic area. In California, LEAs serve as the primary organizational units through which state education policy is translated into local practice.

*Next Generation Science Standards (NGSS)* are a set of K-12 science education standards developed from the *Framework for K-12 Science Education* (NRC, 2012) that emphasize three-dimensional learning through the integration of science and engineering practices, disciplinary core ideas, and crosscutting concepts. Adopted by California in 2013, the CA-NGSS represent a fundamental shift away from rote memorization toward the application of scientific thinking for personal and social purposes (CDE, 2023; Rutherford & Ahlgren, 1989).

*Rigor* in education refers not simply to the difficulty of content but to the depth of understanding, relevance, and critical thinking required of students, ideally scaffolded in ways that are accessible and affirming across cultural contexts (Hammond, 2015).

*Academic Institutionalized Culture* encompasses the dominant norms, values, routines, and expectations embedded within educational institutions that often reflect white, middle-class, monocultural standards and may marginalize students whose cultural practices differ from those norms (Ray, 2019; Ladson-Billings, 1995).

**Summary**

This chapter has established the foundation for a study examining the systemic and cultural barriers that rural educational leaders encounter in increasing access to science education for minoritized students. Beginning with the historical roots of scientific literacy as a democratic imperative, the chapter traced the evolution of science education policy from the Cold War era through the publication of *Science for All Americans* (Rutherford & Ahlgren, 1989), the development of *A Framework for K-12 Science Education* (NRC, 2012), and the adoption of the Next Generation Science Standards in California in 2013. Despite the promise of these reforms, more than a decade of implementation has yielded persistently inequitable outcomes, with 69.82% of California students assessed in science performing below satisfactory levels (CDE, 2023). These outcomes are further compounded in rural contexts, where geographic isolation, resource scarcity, staffing instability, and cultural mismatch converge to disenfranchise historically marginalized students from meaningful participation in science. The rationale and significance of this study were established by situating rural education within the broader national imperative for STEM innovation and equitable access. The researcher's positionality was articulated to make transparent the lived experience and professional knowledge that shape this inquiry, and key terminology was defined to provide a shared conceptual language for the discussion that follows.

The chapters that follow build systematically on this foundation. Chapter Two presents a review of the literature that examines the theoretical and empirical landscape informing this study, including scholarship on rural education, culturally responsive and sustaining pedagogy, science education reform, and educational leadership in high-needs contexts. Chapter Three details the methodology and methods employed in this study, including the epistemological framework, participant selection process, data collection procedures, and analytical approach. Chapter Four presents the research design in full, including the semi-structured ethnographic framework and the criteria used to identify and qualify participants. Chapter Five presents the findings that emerged from participant interviews, organized around the central themes surfaced through data analysis. Chapter Six provides an analysis of those findings in relation to the theoretical frameworks and existing literature introduced in Chapter Two. Chapter Six offers recommendations for practice, policy, and future research as well as presents the conclusions of the study, returning to the central research question to synthesize what has been learned and what remains to be understood.

# Chapter Two: Literature Review

## Theoretical Frameworks

This study was guided by three complementary theoretical frameworks that together provided a multilayered analytical lens for examining three distinct domains of literature: rural educational leadership, science implementation through the NGSS (Next Generation Science Standards), and the needs of minoritized students. The frameworks themselves, operating at the organizational, leadership, and instructional levels, were distinct from both the domains of literature they helped analyze and the interdomain themes that emerged from across those domains. Together, the frameworks provided the interpretive architecture through which the domains were examined and the themes were understood.

The sequencing of these three domains was intentional. Rural educational leadership was positioned first because without it, conversations about what minoritized students needed in science education had inevitably defaulted to surface-level solutions, most notably, school garden programs that, while well-intentioned, did not address the full scope of access to NGSS aligned instruction challenges facing rural students. Rural students may have had proximity to nature and land, but proximity was not instruction. The absence of a rural leadership perspective had allowed this conflation to persist, substituting experiential familiarity with the natural world for the rigorous, culturally grounded science instruction that rural minoritized students deserved and were entitled to. It was only by beginning at the rural leadership level that this study could interrogate the systemic conditions that had allowed such substitutions to stand in place of genuine instructional equity.

The second domain explored the implementation of NGSS across California followed next because the rollout of the Next Generation Science Standards was a statewide collaboration that required coordinated action across agencies, county offices, and local educational agencies simultaneously. Understanding how that rollout unfolded, and where it succeeded or fell short in reaching rural and minoritized communities, was essential context for interpreting the leadership and instructional dynamics that this study examined. The statewide nature of NGSS implementation meant that the barriers and affordances rural leaders encountered were shaped not only by local conditions but by the broader systemic architecture of California's science education reform effort.

The final domain clarified the needs of minoritized students and was positioned third and deliberately so. The positioning of this final domain represents the fine grain specificity of the leadership context, field of study and public education students we are discussing. The needs of minoritized or marginalized students is the final domain to understand within the broader educational context. Before arriving at what minoritized students needed in science education, this study first established the rural context in which those needs were situated and the transformative power of science and STEM education as a vehicle for equity and social mobility. Rural context mattered because the conditions of rurality isolation, under-resourcing, and cultural specificity shaped what was possible and what was constrained in science instruction. The power of science and STEM education mattered because it established the stakes: science was not a peripheral subject but a gateway to economic opportunity, civic participation, and self-determination. Only after these two domains were established did it become possible to fully articulate what minoritized students in rural settings needed and what they had been systematically denied. Sequencing the literature in this way ensured that the needs of minoritized students were not treated as an isolated problem of individual deficiency but were understood as the predictable outcome of systemic conditions that rural educational leaders were positioned to address.

**Figure 1**
*Theoretical Frameworks by Analytical Level and Domain of Literature*


The Theory of Racialized Organizations (Ray, 2019), drawn from organizational theory, provided the macro-level lens through which the systemic dimensions of this study were examined. Ray argued that organizations were not racially neutral structures that merely reflected the biases of individuals within them, but were themselves racialized by design embedding racial hierarchy into their rules, norms, and resource distribution in ways that advantaged some groups while marginalizing others. In the context of this study, Ray's framework was applied to rural educational systems to identify where systemic barriers were embedded in the organizational structures, policies, and practices that shaped science education for minoritized students. Rather than locating the problem in individual actors, this framework directed analytical attention to the institutions themselves and the racialized logics that sustained inequity across time.

The Emerging Framework for Inclusive Educational Leadership developed by Young and Arnold (2020), drawn from education, provided the meso-level lens through which rural leadership was examined. The framework organized analysis around three unique components: place, preparation, and practice. In this study, place was connected to the scholarship on educational leadership in rural locations, where the geographic, cultural, and relational dynamics of rurality shaped both the possibilities and constraints of leadership work. Preparation was connected to the literature on science teacher preparation and the instructional shifts demanded by the Next Generation Science Standards. Practice was connected to the scholarship on culturally relevant teaching and the needs of minoritized students. This framework was particularly well suited to the rural context examined in this study because it provided clarity on the compressed and overlapping expectations placed on rural leaders, who routinely wore multiple hats and navigated responsibilities that would have been distributed across many roles in larger, more resourced systems (McHenry-Sorber & Sutherland, 2020).

Culturally Relevant Pedagogy (CRP), developed by Ladson-Billings (1995) and also drawn from education, provided the micro-level lens through which classroom instruction was examined. CRP contained three interdependent tenets that together defined what equitable teaching required. The first tenet was student learning, which extended beyond academic achievement to encompass students' intellectual growth, moral development, and capacity to problem-solve and reason recognizing that science education, at its best, was a vehicle for developing the whole student. The second tenet was cultural competence, which equipped students with the skills to affirm and appreciate their culture of origin while developing fluency in at least one other cultural context.  This tenet was a particularly significant dimension in rural science education, where students' deep connections to land, place, and community represented a largely untapped epistemological resource. The third tenet was critical consciousness, which developed students' ability to identify, analyze, and solve real-world problems, especially those that produced societal inequalities positioning science not as a neutral body of knowledge but as a tool for understanding and transforming the conditions of one's own life and community.

For rural educational leaders, CRP was not simply an instructional framework to be handed to teachers; it was a call to cultivate critical consciousness within their own leadership practice. Equitable science education in rural contexts required leaders who could recognize the ways in which dominant academic institutionalized culture marginalized the knowledge, experiences, and ways of knowing that minoritized students brought to science learning, and who were positioned to disrupt those patterns through deliberate, culturally grounded instructional leadership. Where Ray's (2019) Theory of Racialized Organizations surfaced the systemic conditions that produced inequity and Young and Arnold's (2020) Inclusive Educational Leadership Framework illuminated how leaders navigated those conditions, CRP directed analytical attention to the instructional practices and relational dynamics that minoritized students encountered daily and to the critical awareness that educators needed to develop to transform them.

Together, these three frameworks created an integrated analytical architecture for this study. Ray's (2019) Theory of Racialized Organizations surfaced the systemic and institutional barriers embedded in rural educational systems. Young and Arnold's (2020) Inclusive Educational Leadership Framework examined how rural leaders navigated those systems across the domains of place, preparation, and practice. And Ladson-Billings' (1995) Culturally Relevant Pedagogy framework illuminated the instructional level where the consequences of systemic inequity most directly manifested in student outcomes. Used in concert, these frameworks allowed this study to move fluidly across organizational, leadership, and instructional levels of analysis, offering a comprehensive view of what equitable science education required in rural contexts.

A notable gap existed in the literature at the precise intersection this study seeks to examine. While scholarship on rural education, science education reform, and culturally relevant pedagogy each represented a robust and growing body of work, the literature had not sufficiently addressed the role of rural educational leaders in specifically supporting the science education of minoritized students. Studies of rural leadership tended to focus on general administrative challenges, staffing, and community engagement without attending to the content-specific demands of science instruction. Studies of science education reform and NGSS implementation tended to focus on teacher practice and curriculum design without centering the leadership conditions that made or impeded equitable implementation. And studies of minoritized students in STEM tended to focus on urban contexts, leaving the rural experience undertheorized and underexamined. What was missing was a sustained examination of how rural educational leaders navigated all of these dimensions simultaneously and in particular, how they supported the development of the complex, multilayered skills that scientific literacy demanded. Scientific literacy as defined by the NGSS was not a simple content mastery but a sophisticated integration of disciplinary knowledge, scientific practices, and crosscutting concepts that required ongoing, culturally informed instructional leadership to develop in all students, and most urgently in those who had been historically excluded from the science education pipeline. This study addressed that gap directly.

## Literature Review Themes

The three domains of literature informing this study rural educational leadership, science implementation, and the needs of minoritized students were each examined independently before being read in conversation with one another. What emerged from that cross-domain reading were three overarching themes that did not belong to any single domain but rose to the top across all three simultaneously, making them interdomain concepts substantiated by the convergence of evidence across the literature as a whole. These themes were distinct geospatial challenges, distinct resource navigation, and distinct relational dynamics. Taken together, they revealed that the challenges of rural science education leadership were not simply scaled-down versions of urban or suburban challenges; they were qualitatively distinct, compounding, and deeply rooted in the geographic, organizational, and relational conditions of rural life. It was precisely because these themes appeared across domains, rather than within any single one, that they carried the analytical weight necessary to illuminate the full complexity of what rural educational leaders navigated in their efforts to increase science education access for minoritized students.

### *Theme One: Distinct Geospatial Challenges for Rural STEM Leaders*

The first theme addressed the geographic and spatial conditions that defined rural educational leadership. Remoteness and geographic isolation were among the most consistently documented features of rural education, shaping not only the physical conditions of schooling but the professional lives of the educators who worked within them. Rural leaders and teachers frequently experienced both geographic isolation defined by physical distance from professional communities, resources, and support networks and professional isolation, which limited access to the collegial exchange, mentorship, and ongoing learning that sustained instructional improvement over time.

Compounding geographic isolation were the infrastructure gaps that characterized many rural communities, including limited broadband connectivity, inadequate road systems, and unreliable access to the technological tools that had become central to science instruction and professional development in the NGSS era. These infrastructure deficits were not incidental — they represented a structural dimension of rurality that directly constrained what was possible in rural science classrooms and what rural leaders could reasonably expect of their educators and students.

The cumulative impact of these geospatial conditions was a profound limitation on collaboration. Rural science educators, and the leaders who supported them, were frequently singleton leaders, singleton teachers, and in some cases singleton districts — meaning there may have been only one science teacher, one curriculum coordinator, or one administrator responsible for science at a given level within a geographic area. This singularity made collaborative professional learning, peer observation, and shared instructional leadership structurally difficult to sustain, further isolating the educators most in need of support.

### *Theme Two: Distinct Resource Navigation for Rural STEM Leaders*

The second theme addressed the resource conditions that rural STEM leaders had to navigate in their efforts to support science education for minoritized students. Rural educational settings were characterized by a persistent lack of both financial and human resources, creating conditions in which leaders had to accomplish complex instructional improvement work with significantly less capacity than their urban and suburban counterparts. This resource scarcity was not simply a matter of budget it reflected a systemic pattern in which rural communities were consistently underfunded and underserved by the broader educational infrastructure.

Central to this theme was what researchers had identified as the research desert cycle, a self-reinforcing dynamic in which the absence of research on rural education led to the absence of targeted policy and funding, which in turn perpetuated the conditions that made rural communities difficult to study and serve (Thier et al., 2021). Rural science education existed within this cycle, remaining undertheorized and unsupported even as the demands of NGSS implementation increased.

Rural leaders also contended with limited absorptive capacity defined as the ability to acquire, assimilate, and retain new resources, knowledge, and practices within an organization (Zuckerman et al., 2018). In rural educational systems, where staffing was lean and leadership roles were compressed, the work of securing and sustaining new resources placed an extraordinary burden on already overstretched leaders. The demands of NGSS implementation made this burden especially acute. The NGSS were written with the need for professional learning explicitly acknowledged, and designing for NGSS adoption required addressing multiple simultaneous considerations around both teacher capacity and student capacity (NRC, 2012). Yet the investments required to build that capacity were substantial. Anderson et al. (2018), in their design-based implementation research project examining three-dimensional learning through the Carbon TIME units, found that while a focused, iterative professional development model produced measurable increases in student capacity, the resource investments required were considerable, raising serious questions about what scalable, equitable NGSS implementation realistically demanded of systems that were already under-resourced.

The question of educator capacity was further complicated by what the literature revealed about the nature of NGSS instructional shifts themselves. Anderson et al. (2018) noted that three-dimensional engagement with science content was not always natural to the ways students had been conditioned to interact with science in transactional, grade-focused classroom environments, placing additional pressure on educators to fundamentally reimagine their instructional practice. Moore (2007) deepened this analysis by revealing how language itself functioned as a gatekeeper in science education, with the discourse of science content — what Gee (1999) termed big "D" Discourse reflecting hierarchical Western ways of knowing that systematically disadvantaged students whose cultural modes of expression had been marginalized by dominant culture. For rural leaders supporting minoritized students, this meant that NGSS implementation was not simply a curricular or logistical challenge it was a deeply cultural one, requiring educators to develop not only content knowledge and pedagogical skill but the critical awareness to recognize how science language and practice reproduced inequity in the classroom.

Madkins and McKinney de Royston (2019) further illuminated this challenge by identifying sociopolitical consciousness, the third tenet of Culturally Relevant Pedagogy, as the component most consistently missing from science instruction. Despite broad acceptance of asset-based approaches like CRP in the field of science education, the researchers found that educators rarely enacted political clarity during instruction, and that science classrooms remained narrowly aligned with white, middle-class norms that marginalized the majority of students they served. The implications for rural leaders were significant: building absorptive capacity in rural science education required not only securing professional development resources but ensuring that those resources cultivated the kind of culturally grounded, politically aware instructional practice that could genuinely reach minoritized students. The NASEM (2024) equity framework, which took a systems-aware approach encompassing teachers, professional learning, and curricula as the major controllable components of science education, affirmed that this work demanded coordinated, structural attention not isolated interventions if it was to produce equitable outcomes at scale.

This challenge was further compounded by high teacher turnover in science-related fields, which disrupted instructional continuity, depleted institutional knowledge, and forced rural leaders into a perpetual cycle of recruitment, onboarding, and rebuilding, leaving little capacity for the sustained instructional leadership that science education reform required. When the educators who had developed the cultural awareness and content knowledge to teach science effectively in rural contexts left, they took with them not only their skills but the relational capital that made culturally relevant science instruction possible in communities where trust was hard-won and slow to rebuild.

### *Theme Three: Distinct Relational Dynamics in Rural STEM Leadership*

The third theme addressed the distinct relational landscape of rural educational leadership. This dimension was both a defining feature of rurality and a critical lever for equity. Rural education was far more complex than commonly perceived, and scholars increasingly argued for frameworks that challenged reductive narratives and engaged the nuanced realities of place.

Azano and Biddle (2019) cautioned against binary framings of rurality and instead called for problem formation rooted in local context and equity, a warning that was particularly relevant in science education, where deficit-oriented assumptions about rural students and communities had too often shaped both policy and practice.

Rural leaders operated within multigenerational communities where history, identity, and political culture were deeply intertwined with educational expectations and norms. Navigating these multigenerational community dynamics required leaders to understand not only the present needs of their communities but the historical relationships between schools and the families they served. This navigation was complicated by the generational conservative political orientations that in many rural California communities shaped attitudes toward science content, curriculum, and the role of public education. Schaller (2024) framed rural discontent within broader threats to democratic stability, describing a political landscape in which distrust of institutions including public schools ran deep and was often weaponized against equity-focused reform efforts. For rural science education leaders attempting to implement culturally responsive, justice-oriented instruction, this political backdrop was not peripheral but central to every equity conversation that had to be navigated.

The tension between locally conservative viewpoints and equity-focused educational goals was one of the most defining and least discussed relational challenges of rural educational leadership. McHenry-Sorber and Sutherland (2020) described the pressure rural leaders faced in honoring local culture while simultaneously striving for district-wide cohesion and equitable outcomes, a tension that was especially acute when the cultural norms of a community conflicted with the rights and needs of its most marginalized students. This was not simply a matter of political disagreement. It was a structural condition of rural leadership in which the same relational proximity that made community trust possible also made it fragile, and in which leaders who centered equity could find themselves at odds with the very communities they were accountable to serve. Grant-Panting (2021) and Joubert and Lensmire (2021) deepened this analysis by foregrounding the urgency of racial justice in rural communities, reminding us that rural was not raceless that the conditions of rurality intersected with race, power, and history in ways that demanded a critical, justice-oriented leadership practice.

Achieving educational equity in this context required more than inclusion; it demanded a transformation in how schools recognized and sustained students' cultural identities. Scholars such as Ladson-Billings (1995) and Gay (2002) emphasized that affirming students' cultural backgrounds was foundational to both academic success and critical consciousness, a view extended by Paris and Alim (2014), who advocated for culturally sustaining pedagogy that did not merely bridge students to dominant academic culture but actively preserved and revitalized the cultural and linguistic practices of historically marginalized communities. Hammond (2015) connected these practices to brain development, demonstrating that cultural affirmation promoted deeper cognitive engagement and positioned students as capable, intellectually powerful learners. In science education specifically, Aikenhead (2001) illustrated how cross-cultural science teaching that integrated students' ways of knowing with Western scientific frameworks created more meaningful and equitable learning experiences, particularly for students whose cultural epistemologies had been historically excluded from the science classroom.

Yet systemic structures persistently marginalized culture through language (Moore, 2007), deficit narratives (Kirchgasler & Yolcu, 2022), and racialized organizational norms (Ray, 2019). These dynamics were especially harmful to students with intersecting identities, such as twice-exceptional minoritized learners whose academic potential was doubly obscured by systems that failed to see them fully (Cormier, 2022). In science and data education, scholars called for structural alignment (Anderson et al., 2018) and human-centered approaches (Lee et al., 2021) that reflected students' lived experiences rather than imposing a monocultural framework on diverse learners. School leaders, as Lewis-Durham and Saastamoinen (2022) noted, had to confront deficit thinking and lead with cultural awareness, recognizing that the beliefs leaders held about students' capacities were themselves a form of systemic barrier when those beliefs were shaped by racialized assumptions. Ultimately, as Tyson and Lewis (2021) argued, student disengagement in science reflected not resistance to learning but resistance to systems that had consistently failed to affirm their cultural identities and intellectual worth.

Rural leaders also navigated a distinctive tension between visibility and vulnerability. In small, tight-knit communities, educational leaders were highly visible public figures whose personal and professional lives were rarely fully separate. Copeland (2013) detailed the burden of wearing many hats as a rural superintendent, where the compression of roles extended not only to administrative responsibilities but to the relational demands of leading in a community where everyone knew everyone. This blurring of professional lines created both opportunity and risk opportunity because relational proximity could deepen trust and community investment in schools, and risk because the same proximity could constrain leaders' ability to advocate for change, challenge entrenched norms, or center the needs of minoritized students without personal and professional consequence. Leadership development tailored to these realities was necessary, as shown in Mette's (2021) review of rural leadership coaching and Wargo et al.'s (2021) analysis of statewide research-practice partnerships that built rural leaders' capacity to navigate exactly these tensions.

Teacher retention added yet another relational layer to this already complex landscape. reframed rural teacher retention not primarily as a compensation or incentive problem but as one rooted in deep relational and place-based commitments; teachers stayed in rural communities when they felt genuinely connected to place, students, and community. This finding had direct implications for rural science education, where high turnover in science-related fields disrupted not only instructional continuity but the relational trust between students and educators that culturally relevant science teaching required. At the policy level, institutional notions of rurality were themselves socially constructed in ways that often reinforced inequality (Crain, 2023), compounding the challenge for leaders who had to navigate systems that were not designed with rural equity in mind and communities that had learned, with good reason, to distrust those systems.

At the foundation of effective rural leadership, however, was relational trust, the deep, sustained relationships between leaders, educators, families, and community members that made transformative work possible in rural contexts. Research identified relational trust as both a distinctive feature of rural educational leadership and its most powerful resource (Harmon et al., 2003; Wargo et al., 2021). For rural science education leaders working to increase access for minoritized students, relational trust was not merely a leadership style, it was the connective tissue through which systemic change became possible in communities where institutions had historically failed the students they were built to serve. It was also, as Showalter et al. (2023) reminded us, the foundation upon which a more equitable and opportunity-rich rural education future had to be built.

**Rationale for This Research**

The three themes surfaced in this literature review: geospatial challenges, resource navigation, and relational dynamics painted a clear and sobering picture of the conditions under which rural educational leaders worked to support minoritized students in science education. Yet the literature, taken as a whole, revealed as much by its silences as by what it addressed directly. The intersection of rural educational leadership, NGSS implementation, and the specific science education needs of minoritized students remained an understudied and undertheorized space. This absence was not neutral. When the experiences of rural minoritized students were absent from the research base, they were also absent from the policy conversations, funding decisions, and professional learning systems that shaped what was possible in rural science classrooms.

This research was needed because the students it concerned could not wait for the literature to catch up. In rural California, where 69.82% of students assessed in science performed below satisfactory levels (CDE, 2023) and where the conditions of rurality compounded the already significant barriers facing minoritized students, the cost of inaction was measured in foreclosed futures in students who were immersed in the natural world but denied the scientific language and frameworks to claim it as their own, and in communities whose capacity for self-determination was diminished by a science education system that was never fully designed with them in mind. By centering the voices and navigational strategies of rural educational leaders, this study contributed to a body of knowledge that was not only academically significant but practically urgent — drawing on three domains of literature, interpreted through three theoretical frameworks, and organized around three interdomain themes that together offered a comprehensive and justice-oriented account of what equitable rural science education leadership required, what it made possible, and what it would take to finally get it right.

# Chapter Three: Qualitative Methodology, Research Design, and Methods

## Introduction

This study seeks to understand the systemic and cultural barriers that rural educational leaders encountered and navigated in increasing access to science education for minoritized and/or marginalized students. Guided by two sub-questions; how rural science educational leaders navigated the complexities of supporting minoritized students in science education, and what systemic barriers science educators faced in aligning NGSS instructional practices to the needs of minoritized students, this study is anchored by the central research question: *What systemic and cultural/historical barriers do rural education leaders encounter and navigate in increasing access to science education for minoritized students?*

This chapter describes the methodological decisions that shaped how this study was designed and carried out. It begins with a discussion of the epistemological and paradigmatic foundations that informed the research approach, followed by a rationale for the selection of semi-structured ethnography as the methodology of choice. The chapter then details the purposeful participant selection process, including the geographic, priority, and functional criteria used to identify and qualify participants. It proceeds to describe the data collection procedures including the interview protocol, consent process, and follow-up methods, before concluding with an explanation of the analytical approach used to identify themes and patterns across participant accounts. Together, these methodological decisions reflect a commitment to rigorous, justice-oriented inquiry that centered the lived experiences of rural educational leaders as the primary source of knowledge about what equitable rural science education required.

## Rationale for Research Design

The purpose of this qualitative, role-based case study was to learn the ways in which rural science education leadership prepared to respond to the needs of educators in supporting NGSS instructional shifts and the needs of minoritized students in rural communities. A qualitative approach was most appropriate for this inquiry because the research questions called for deep, contextual understanding of how rural leaders experienced, interpreted, and navigated complex systemic and cultural conditions, the kind of understanding that numerical data alone could not capture. Qualitative inquiry made it possible to center the voices, perspectives, and navigational strategies of rural educational leaders as the primary source of knowledge, honoring the complexity of their work rather than reducing it to measurable outcomes.

A role-based case study design was selected because the participants shared a defined set of leadership functions within a bounded geographic and policy context: rural California counties designated by the California Rural Task Force and prioritized through PPIC infrastructure data. This shared role-based context made it possible to examine the commonalities and tensions across participant experiences while remaining attentive to the local and relational specificity that defined rural educational leadership. Role-based case study methodology was particularly well suited to this inquiry because it allowed the study to move beyond the individual and attend to the structural and cultural conditions that shaped how participants in similar leadership positions navigated similar challenges across different rural contexts.

The inquiry, designed to explore how rural science leadership interacted with and responded to the needs of minoritized students, prompted the following research questions:

*RQ1: What systemic barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?*

*RQ2: How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?*

Taken together, these questions led to the central inquiry of this study: *What systemic and cultural/historical barriers do rural education leaders encounter and navigate in increasing access to science education for minoritized students?*

**Research Site**

States within the United States employ different structures for education. California utilizes a structure for educational services disseminated through 58 county offices of education, with elected superintendents leading all but five, which are appointed superintendencies. Due to the collapsed levels of leadership characteristic of rural education agencies (Copeland, 2013), a school district in rural California could also serve simultaneously as the county office of education, further compressing the leadership structures that defined the study's context.

The researcher's challenge was to locate rural school districts within California's 58 counties in a way that reflected the themes of resource scarcity, geographic isolation, and relational structures identified in the literature. National rural designations such as those used in the *Why Rural Matters* report (Showalter et al., 2023) were considered but found to be insufficient for this purpose. The National Center for Education Statistics (NCES) designations of rurality were urban-centric by design (Thier et al., 2021), defining rurality primarily through proximity to urban locations rather than through the resource, geographic, and relational conditions that characterized the rural contexts most relevant to this study. By centering proximity to urban areas as the primary marker of rurality, the NCES framework inadvertently marginalized the very conditions — scarcity, isolation, and compressed relational structures that made rural educational leadership qualitatively distinct from its urban and suburban counterparts.

This led to the use of the California Rural Counties Task Force (2025) framework, which defined a county as rural if it had a total population under 250,000 and lacked a single urbanized area of more than 50,000 residents. This definition differed meaningfully from the NCES locale codes, which classified schools individually as rural fringe, rural distant, or rural remote based on geographic proximity to urban centers (Showalter et al., 2023). A county-based approach was most appropriate for this study because educational leadership in California was organized and supported through county offices of education, which served as intermediaries between the state and local districts. Using counties as the unit of rural designation, therefore reflected the administrative, policy, and professional development structures within which rural leaders operated. While this framework did not capture intra-county variation in rurality, it ensured that participant selection aligned with the governance structures that shaped leaders' experiences, making it a methodologically and contextually relevant choice.

**Participant Selection and Data Sources**

Purposive sampling was used to select participants for this research and allowed for the selection of individuals with expertise in science education, as demonstrated by oversight or critical support of rural county and district science education functions for single or multiple local education agencies (LEAs). This approach ensured that all participants brought substantive, role-based knowledge of rural science education leadership to the study rather than general familiarity with the field.

Critical job functions were developed in collaboration with the California County Superintendents' Curricular and Improvement Support Committee (CISC) Science Subcommittee Chair and reflected the essential roles of a science education leader recognized by the statewide CISC Science Subcommittee. The CISC allowed each of the 58 county offices of education to designate individuals as members of the Science Subcommittee based on these essential functions.

The five essential functions of rural science education leadership each carried significant weight within this county-based structure. The functions of disseminating information from the CDE and State Board to the LEA and elevating the contextualized needs of the LEA back to the state both required the designated individual to engage in the work of buffering and bridging (Zuckerman et al., 2018), absorbing and translating policy directives in ways that protected local capacity while simultaneously advocating upward for the specific needs and conditions of rural communities. The function of advocating for public science education intersected with the relational aspects of rural educational leadership by positioning science education as a place-based and place-conscious community endeavor (McHenry-Sorber & Sutherland, 2020), one in which the science education leader served not only as a policy implementer but as a connector between the scientific aspirations of the state and the lived realities of rural students, families, and communities.

Participants were required to perform at least three of the following five essential functions, each of which carried embedded decision-making authority regarding science education for the LEA:

- **Provides or selects Professional Learning**. This essential function encompassed capacity building for single or multiple school sites or districts, including acting in the role of Trainer of Trainer, training teachers and other staff in science education content or practices, and coaching classroom educators or school staff in science education content or practices.

- **Disseminates information from the California Department of Education (CDE) and State Board of Education back to the LEA**. This function required the designated individual to be trusted and recognized by both CISC and the LEA as having the capacity to act as a conduit between state policy and local practice, a process that frequently required buffering and bridging (Zuckerman et al., 2018) between organizational levels.

- **Elevates contextualized needs of the LEA to the CDE and State Board of Education**. This function served as the inverse of the dissemination role, engaging the designated individual in state-level conversations that required supplying both quantitative and qualitative data regarding the status of science education. The bridging process was particularly critical here as the designated individual presented the options, resources, and needs of their LEA to state-level decision makers.

- **Plans and implements science-related events for the LEA**. This essential function included organizing and executing science and STEM-related activities such as Science or STEM Fairs, Dinner with a Scientist events, Mobile Science Labs, and Girls Who

Code programs, positioning science education as a visible and valued community endeavor.

- **Advocates for the need for public science education**. This function described a critical messaging and communication role carried by science education leads. It intersected with the relational aspects of rural educational leadership by positioning science education as a place-based and place-conscious community endeavor (McHenry-Sorber & Sutherland, 2020), one in which the science education leader served not only as a policy implementer but as a connector between the scientific aspirations of the state and the lived realities of rural students, families, and communities.

Each of these essential functions took on additional weight when considered within the role of the county office as a system collaborator in the implementation of the CA-NGSS. Embedded within each function was the decision-making authority that rural science education leaders exercised on behalf of their LEAs authority that, in more resourced systems, would have been distributed across multiple specialized roles but that in rural contexts was concentrated within a single individual navigating the compressed demands of rural educational leadership.

**Participant Demographics**

Eleven participants *(N = 11)* took part in this study, each identified by a tree-based pseudonym selected by the participant to honor the natural landscape of rural California while protecting participant confidentiality. As noted in the research design, the visibility of rural educational leaders within their communities made anonymity a particularly important ethical consideration, and the use of nature-based pseudonyms reflected both a commitment to participant protection and a symbolic acknowledgment of the rural contexts from which participants led.

Participants represented a range of rural California regions, job function levels, and demographic backgrounds. The majority of participants identified as White women, with one participant identifying as Hispanic/Latina women and three participants identifying as White men. Job functions ranged from three to five, reflecting the varying degrees of leadership breadth and role compression characteristic of rural educational contexts. Several participants served at the statewide level, while others were situated within specific regional designations aligned with the California Rural Task Force county classifications used in the participant selection process.

The following table summarizes participant demographics across pseudonym, region or statewide rurality ranking, number of job functions performed in the current role, and ethnicity and gender:

**Table 1**
*Participant Demographics*

| Pseudonym | Rurality Ranking or Region | Job Functions | Ethnicity/Gender |
|---|---|---|---|
| Valley Oak | Region 2 & 3 | 3 | W/F |

| | | | |
|---|---|---|---|
| Torrey Pine | Region 9 | 4 | W/M |
| Ginkgo | Ranked 17 | 5 | W/M |
| Pine | Ranked 2 | 4 | W/F |
| Douglas Fir | Ranked 6 | 3 | W/F |
| Lemon | Statewide | 5 | H/F |
| Juniper | Ranked 23 | 5 | W/F |
| Oak | Ranked 10 | 4 | W/F |
| Incense Cedar | Ranked 4 | 5 | W/M |
| Redwood | Ranked 1 | 3 | W/F |
| Magnolia | Statewide | 5 | W/F |

*Note. W = White, H = Hispanic/Latina, F = Female, M = Male*

The participant selection process prioritized counties designated as Tier 1, the most rural of the rural, based on the crosswalk between California Rural Counties Task Force county designations and Public Policy Institute of California infrastructure needs data. The six Tier 1 prioritized rural counties were Alpine, Mariposa, Modoc, Plumas, Sierra, and Trinity. Of these six counties, four served as interview sites for this study: Alpine, Mariposa, Plumas, and Trinity, representing 67% of California's most rural county leadership leading science education in California. The remaining two Tier 1 counties, Modoc and Sierra, were not represented among the study's participants, reflecting the practical constraints of rural research including the limited availability of leaders with the time and access to participate and the geographic and professional isolation that characterizes the most rural educational contexts. The concentration of interview sites within Tier 1 counties strengthened the study's claim to examining rural science education leadership at its most acute in the communities where the compounding effects of rurality, resource scarcity, and geographic isolation were most pronounced and where the need for equitable science education leadership was most urgent.

A second tier of prioritized rural counties, Tier 2, was also identified through the participant selection process, comprising seventeen counties that met the rural designation criteria but ranked below Tier 1 counties in terms of infrastructure deficits and rural task force priority indicators. The Tier 2 counties were Amador, Calaveras, Lassen, Siskiyou, Tehama, Inyo, Mendocino, Mono, Del Norte, San Benito, Glenn, Colusa, Tuolumne, Lake, Shasta, Madera, and Humboldt. Of these seventeen counties, three served as focal sites for this study: Siskiyou, Glenn, and Humboldt. Together, the Tier 1 and Tier 2 interview sites represented a geographically diverse cross-section of rural California's science education leadership landscape spanning the far north, the Central Valley, and the coastal ranges and captured the range of rural conditions within which the study's participants led. The inclusion of both Tier 1 and Tier 2 counties in the participant pool ensured that the study's findings were not limited to the most extreme expressions of rurality but reflected the broader spectrum of rural science education leadership challenges across California.

A third tier of participants, Tier 3, extended the study beyond county-level leadership to include individuals operating at the statewide level. Tier 3 represented rural science education leadership with a statewide scope, encompassing organizations and initiatives positioned to bridge local rural contexts within California's broader science education infrastructure. The three entities comprising Tier 3 were the CA NGSS Collaborative, the California County Superintendents Educational Services Association (CCSESA) Science Lead, and the California Science Project. Of these three, two served as interview sites for this study: the CA NGSS Collaborative and the California Science Project. The inclusion of statewide participants was a deliberate methodological choice that reflected the reality that rural science education leadership did not operate in isolation from state-level policy, professional learning, and implementation support structures. Leaders operating at the statewide level occupied a unique vantage point situated at the intersection of policy intent and local practice, and their perspectives provided essential context for understanding how rural county and district leaders navigated the demands of NGSS implementation and equity-centered science education. Together, the three tiers of participants created a layered and comprehensive portrait of rural science education leadership across California, from the most isolated Tier 1 counties to the statewide organizations charged with supporting the field as a whole.

**Data Collection Procedures**

Participants for this study were initially recruited through public website information provided by the California Department of Education. The recruitment method was unproductive as high turnover of positions, medical leave, and other realities created insurmountable challenges to securing interviews. The subsequent method was a purposeful snowball recruitment strategy in which initial participants were asked to recommend others who met the study's selection criteria, allowing the sample to expand organically through professional networks within the rural science education leadership community. Recruitment took place in the spring of 2025 and was guided by the location, priority, and functional job survey criteria described in the research design. This approach was particularly well suited to the rural context of this study, where the professional networks of science education leaders were often small, geographically dispersed, and relational in nature, making snowball sampling an effective and contextually appropriate means of identifying participants who had not been reachable through more formal recruitment channels.

Semi-structured interviews were conducted via Zoom, allowing for geographic flexibility across rural California while maintaining the depth and interactivity of face-to-face conversation. The semi-structured format provided a consistent interview framework while allowing participants the freedom to elaborate, redirect, and share experiences that extended beyond the prepared questions, a design choice that reflected the study's commitment to centering participant voice and honoring the complexity of rural science education leadership as it was lived and practiced.

Interview recordings were viewed, listened to, and transcribed multiple times to ensure accuracy and to allow the researcher to develop a deep familiarity with the data before coding began. All recorded data were stored on a secure computer with embedded anti-theft technology, protecting participant confidentiality throughout the research process. Over the course of several months, the interview data were reviewed and coded using two complementary approaches. Thematic coding was used to identify overarching ideas and patterns that emerged consistently across multiple participant interviews, surfacing the interdomain themes that organized the findings of this study. *In vivo* coding was employed when participant language itself provided increased clarity to capture the specific words, phrases, and framings that informants used to describe their experiences, and preserving the authenticity and cultural specificity of their accounts.

Codes for participant data were developed using the distinct geospatial challenges, resource challenges, and relational challenges navigated by rural educational leaders to categorize generally across experiences. As participants shared their stories, the specific codes within each of the challenges emerged iteratively. Similarities of experience for rural STEM leaders supported coding of geospatial challenges into geographic isolation, infrastructure gaps, and professional isolation. Within distinct resource challenges for rural STEM leaders, codes were developed to capture issues of the professional learning demands of NGSS, science instructional materials, multiple role expectations, and issues of scalability. The codes for the distinct relational dynamics for rural STEM leaders emerged through careful analysis of participant accounts of both the challenges and rewards of learning science in rural spaces. Participants who had previously worked in larger systems were most aware of the distinct navigation necessary in rural spaces.

**Data Analysis**

Data analysis for this study was conducted as an iterative, recursive process grounded in the transformative and postmodern interpretive framework described later in this chapter. Rather than treating analysis as a discrete phase that followed data collection, analysis began during the data collection process itself, as the researcher engaged in active listening, reflective note-taking, and preliminary pattern recognition across interviews as they were conducted. This approach was consistent with the qualitative, role-based nature of this study, in which meaning-making was understood as co-constructed through the relational process of inquiry rather than extracted from a static data set after the fact.

Interview recordings were reviewed, listened to, and transcribed multiple times prior to formal coding, allowing the researcher to develop deep familiarity with the texture, tone, and specificity of each participant's account before imposing any analytical structure upon it. This repeated immersion in the raw data was a deliberate methodological choice, grounded in the recognition that the lived experiences of rural science education leaders could not be fully honored through a single pass of reading but required sustained, attentive engagement with each participant's account in its entirety.

Formal analysis proceeded through two complementary coding approaches applied across multiple rounds of data review. Thematic coding was used to identify overarching patterns and ideas that emerged consistently across multiple participant accounts, surfacing the interdomain themes that organized the findings of this study. Codes were initially developed deductively, drawing on the three interdomain themes identified in the literature review, distinct geospatial challenges, distinct resource navigation, and distinct relational dynamics, as organizing categories through which participant experiences could be examined and compared. Within each of these categories, specific codes emerged inductively as participants shared their accounts, with geospatial challenges coding into geographic isolation, infrastructure gaps, and professional isolation; resource navigation challenges coding into professional learning demands, science instructional materials, multi-role expectations, and issues of scale; and relational dynamics coding into rural community expectations, rural politics, social and professional class divides, language-based marginalization, cross-content marginalization, and local partnerships.

In vivo coding was employed alongside thematic coding to preserve the specific words, phrases, and framings that participants used to describe their experiences. This approach was particularly important in a study centered on the lived experiences of rural science education leaders, whose language carried cultural and contextual specificity that paraphrase alone could not adequately capture. In vivo codes served both as evidentiary anchors for the thematic findings and as a methodological commitment to the fidelity and authenticity of participant voice throughout the analysis.

The coding process was applied iteratively across multiple rounds of data review. An initial round of open coding allowed patterns to surface from the data without the constraint of predetermined categories. Subsequent rounds of focused coding refined and consolidated those patterns, collapsing overlapping codes, distinguishing emergent codes from anticipated ones, and identifying the relationships between codes that ultimately produced the findings reported in Chapters Four and Five. Throughout this process, the researcher maintained analytic memos — written reflections on emerging interpretations, points of tension in the data, and the ways in which her own positionality as a Black female statewide science education leader shaped her reading of participant accounts. These memos served as both an analytical tool and a reflexivity practice, ensuring that interpretive decisions were made transparently and could be examined as part of the study's audit trail.

Member checking was used as a validity strategy during and following the analysis process. Rather than providing written summaries, participants were informed that interview recordings were available upon request, allowing them the opportunity to review, clarify, and extend the researcher's interpretations of their own accounts. This process was consistent with the study's commitment to co-constructed knowledge and ensured that the analytical conclusions of the study reflected the intended meanings of participants rather than the researcher's unexamined assumptions.

Findings were ultimately organized around the two research questions that structured this study. Findings addressing Research Question One — the systemic and cultural/historical barriers to equitable rural science education, are presented in Chapter Four. Findings addressing Research Question Two - the navigational strategies rural science education leaders developed in response to those barriers, are presented in Chapter Five. Together, these findings represent the interpretive conclusions that emerged from the convergence of eleven participant accounts, three theoretical frameworks, and the iterative, reflexive analytical process described in this section.

The following table summarizes the coding structure that emerged across the three interdomain themes, including the research questions each code addressed, a description of each code, and the related literature that informed its development.

**Table 2**
*Coding Structure for Rural STEM Leadership Themes*

| Research Question | Category/Code | Description | Related Literature |
|---|---|---|---|
| ***Distinct Geospatial Challenges for Rural STEM Leaders*** | | | |
| RQ1-What system barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?<br><br>RQ2-How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education? | *Geographic Isolation* | Geographic isolation refers to the population scarcity relative to land. Lack of proximity is a key determinant. | Campbell (1986); Thier et al. (2021) |
| | *Infrastructure Gaps* | Physical distance considerations that limit access to infrastructure supports and essential services. Infrastructure gaps make travel to and within communities difficult. | Campbell (1986); Showalter et al. (2023); Zuckerman et al. (2018) |
| | *Professional Isolation* | Professional isolation encompasses both educators and administrators who lack peer networks and support systems in doing their work. As classroom teachers are often also site and district leaders, this code will denote (T) when specifically addressing a classroom teacher or (A) when addressing a site, district and/or county office administrator. | Campbell (1986); Copeland (2013); Wargo et al. (2021); Seelig & McCabe (2021) |
| ***Distinct Resource Navigation for Rural STEM Leaders*** | | | |
| RQ1-What system barriers do science educators face in aligning NGSS instructional practices | *Need for Professional Learning (PL) in Science/Professional Learning Demands of NGSS* | Next Generation Science Standards (NGSS) reform anticipated that sustained, high-quality PL in science would be necessary for effective implementation | Allensworth, Cashdollar, & Cassata (2022); CDE, 2016 |

| | | | |
|---|---|---|---|
| to the needs of minoritized students?<br><br>RQ2-How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education? | *Science Instructional Materials/Inconsistent Implementation* | NGSS aligned instructional materials are often challenging to use for educators who have not had training on the instructional shifts required of NGSS. Lack of adopted materials and/or training to support the adoption. | Allensworth, Cashdollar, & Cassata (2022); Crain (2023) ; McHenry-Sober & Sutherland (2020), Starr et al.(2019); Emergent |
| | *Multi-Role Expectations/Many Hats* | Education leaders often are required to juggle multiple roles due to smaller staff. This often leads to stress and overload for educators and system/content leaders. | Copeland (2013); McHenry-Sorber & Sutherland (2020) |
| | *Scale or Not To Scale* | Leaders often spoke of small wins that improved a system based on individuals but this was often mentioned as problematic due to it being unknown if the innovation would outlast current administration. How do we get our other schools/classes to participate? | Emergent |
| ***Distinct Relational Dynamics in Rural STEM Leadership*** | | | |
| RQ1-What system barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?<br><br>RQ2-How do rural science educational | *Rural Community Expectations/Multigenerational* | The closeness of rural education leaders combined with a multigenerational family and local ties creates high visibility and increased vulnerability for rural educational leaders in science. | Copeland (2013); Campbell (1986); Harmon (2017); Wargo et al. (2021) |
| | *Rural Politics* | Conservative politics in rural communities often | Joubert & Lensmire (2021); |

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| leaders navigate the complexities of supporting the needs of minoritized students in science education? | | frames equity-focused and science based practices as an ideological threat, making it difficult for educators to implement. | Schaller & Waldman (2024) |
| | *Social/Professional Class Divide* | Tensions between the agendas of those who own (farmers) and those who work (laborers) the land. This tension places out in how science initiatives are selected and supported and which students are allowed access. Often parents who work in science based careers also are seen as the owners of knowledge. | Emergent |
| | *Marginalized due to language barrier* | Students who find themselves left without access to science instruction due to a language of origin other than English. | Anderson, Wright, & Gotwals (2023); Moore (2007); Philip & Azevedo (2017) |
| | *Marginalization across contents/systems* | Students receiving Special Education services, Indigenous student populations, limited English proficiency student populations and to a lesser extent, homeless students were discussed often as the marginalized within the school system and across content areas. | Philip & Azevedo (2017); Paris & Alim (2014); NASEM (2022, 2024) |
| | *Local Partnerships* | Local, place-based organizations who have science and/or environmental expertise work with school sites to provide programming, coaching and supplemental | Ricket, Yahn, and Bentley (2023); Harmon (2017); Seelig & McCabe (2021); Emergent |

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| | | experiences. | |

**Methodological Approach and Interpretive Framework**

This study is grounded in a transformative and postmodern philosophical framework in which the boundary between researcher and researched was understood not as a fixed line but as a permeable space through which subjective and objective realities emerged together. Within this framework, knowledge was not extracted from participants but co-constructed through the relational process of inquiry itself, a process in which participation between researchers and the communities or individuals studied was not incidental but central to the validity and integrity of the research. This philosophical orientation was not simply a methodological preference; it reflected a deeply held belief that the most rigorous and ethical approach to understanding the lived experiences of BIPOC and marginalized communities in rural contexts was one rooted in genuine collaboration, mutual accountability, and the recognition that the researcher's own positionality shaped every dimension of the inquiry.

Through the lens of postmodernism, this study sought to excavate community funds of knowledge (Vélez-Ibáñez & Greenberg, 1992) the historically accumulated and culturally developed bodies of knowledge and skills essential for collective and individual functioning and wellbeing as a means of understanding the individual and community constraints on science education in rural contexts. The desire to understand the lived science experiences of BIPOC students in rural areas led to an examination of the intentions and navigational strategies of the educational leaders placed at the helms of their rural districts. It was through this examination that the depth and complexity of rural science education leadership came into focus, not as a set of administrative functions but as a profoundly human and politically situated practice. This research deepened a commitment to a methodological approach designed not merely to describe but to cause reflection in the researcher, in the participants, and ultimately in the field.

Central to this interpretive framework was a belief in the power of knowledge to change the way in which we think about ourselves, other individuals, and the problems we collectively face. The knowledge base was understood to be most effective when it acknowledged where we were currently situated in history and recognized that specific historical conditions had produced specific present-day realities, and that understanding those realities required attending to the structural, cultural, and political forces that had shaped them. The purpose of this research was not simply to document what existed but to inform and call people to the action of improving lives, a purpose that demanded a methodological approach capable of honoring the full humanity and complexity of the communities it sought to serve.

This dissertation provides the research context and methodology for collecting data, a theoretical framework for interpreting data, a review of relevant literature across three domains, and findings from this study. The findings reveal a need for educational leaders to center equity in their leadership development for the purpose of supporting educators to negotiate the innovations of NGSS. The findings also revealed a need for teachers to center equity and sociopolitical consciousness (Ladson-Billings, 1995) in their teaching of science. Lastly, the findings reveal a gap in the conversation around the cultural and political realities of teaching science in rural spaces, a gap that this study sought to begin to fill.

### Issues of Trustworthiness

Trustworthiness in qualitative research is established through attention to four criteria: credibility, dependability, confirmability, and transferability (Lincoln & Guba, 1985). Each of these criteria was addressed through deliberate methodological choices made throughout the design and execution of this study.

Credibility, the qualitative equivalent of internal validity, was addressed in part through the depth and rigor of the literature review, which established a robust theoretical and empirical foundation for the study's conceptual framework, research questions, and interpretive approach. By grounding the study in three distinct but interconnected domains of literature and organizing analysis through three complementary theoretical frameworks, the literature review ensured that the researcher's interpretations of participant data were anchored in a well-substantiated body of scholarly knowledge. Credibility was further supported through triangulation, the use of multiple data sources, coding approaches, and analytical perspectives to cross-check and strengthen the emerging findings. The combination of thematic coding and in vivo coding, applied across multiple rounds of data review, allowed patterns to be verified from more than one analytical angle (Creswell & Creswell, 2018). Peer review also contributed to credibility, as ongoing dialogue with colleagues and scholarly mentors provided external perspectives that challenged assumptions, surfaced blind spots, and refined interpretive conclusions throughout the research process.

Dependability, the qualitative equivalent of reliability, was addressed through the consistent and transparent application of the study's data collection and analysis procedures. The use of a semi-structured interview protocol across all participants ensured a baseline of consistency, while the iterative coding process moving from inductive to deductive analysis across multiple rounds of review created an auditable trail of analytical decision-making that could be examined and evaluated by others.

Confirmability, the qualitative equivalent of objectivity, was addressed through reflexivity. Throughout the study, the researcher maintained an ongoing commitment to examining and making transparent the ways in which her own positionality as a Black female statewide science education leader with deep professional ties to rural California shaped her interpretive lens. Rather than treating this positionality as a source of bias to be eliminated, the researcher understood it as a dimension of the inquiry that required conscious, ongoing reflection, ensuring that participant voices were represented with fidelity to their intended meaning rather than being filtered through unexamined assumptions.

Transferability, the qualitative equivalent of external validity, was addressed through the richness and specificity of the study's contextual description. By providing detailed accounts of the participant selection process, the geographic and policy context of rural California science education leadership, and the structural conditions within which participants led, this study generated the thick description necessary for readers to assess the degree to which its findings might apply to other rural science education leadership contexts beyond California (Creswell & Poth, 2018).

### Ethical Considerations

The ethical dimensions of this study were carefully considered at every stage of the research process, from participant selection through data collection, analysis, and reporting. As a study involving human participants, this research was conducted in full compliance with the ethical standards established by the Institutional Review Board (IRB) of the university through which this research was conducted. IRB approval was obtained prior to the initiation of any data collection activities, ensuring that the study's design, participant recruitment procedures, consent processes, and data handling protocols met the institutional and federal standards for the ethical treatment of human research participants.

Informed consent was a foundational ethical commitment of this study. All participants were provided with a consent form prior to their interview that clearly described the purpose of the study, the nature of their participation, the voluntary nature of their involvement, their right to withdraw at any time without consequence, and the measures that would be taken to protect their confidentiality. Participants were given adequate time to review the consent form and ask questions before agreeing to participate. No data collection took place until consent was confirmed.

Confidentiality was a particularly important ethical consideration given the visibility of rural educational leaders within their communities. As noted throughout this study, rural leaders were highly visible public figures whose professional and personal lives were rarely fully separate, and who could be identified with relatively few details. To protect participant confidentiality, all participants were assigned tree-based pseudonyms, and any identifying details that could have connected a participant to a specific community, district, or institution were removed or generalized in the reporting of findings. Data were stored on a secure computer with embedded anti-theft technology, and access to raw interview data was limited to the researcher throughout the study.

The researcher's own positionality as a Black female statewide science education leader with deep professional ties to the rural California communities represented in this study introduced both opportunity and ethical responsibility. The relational familiarity that the researcher brought to the inquiry created conditions of trust and candor that enriched the data, but it also required ongoing reflexive attention to ensure that the researcher's own knowledge, experiences, and commitments did not foreclose participant meaning or introduce undue influence into the interpretive process. Throughout the study, the researcher maintained a commitment to transparency, reflexivity, and the ethical obligation to represent participant voices with accuracy, care, and fidelity to their intended meaning.

**Limitations**

One notable limitation of this study was the challenge of accessing rural science education leaders directly through traditional recruitment channels. The high turnover rates and multiple-hat demands characteristic of rural educational leadership (Copeland, 2013) meant that identifying and reaching individuals who currently held active rural science education leadership roles was not straightforward. Many potential participants had transitioned out of their roles, taken on additional responsibilities that left little time for research participation, or were simply difficult to locate through county and district directories alone. For this reason, the statewide science education community network had to be engaged as a recruitment infrastructure, drawing on established professional organizations and initiatives, including the California Science Project (CSP), the California Mathematics, Science, and Computer Science Initiative (CAL-MSCS), the California County Superintendents Educational Services Association (CCSESA), and the California Regional Environmental Education Community (CREEC), among others. While this approach ultimately produced a rich and well-qualified participant pool, it introduced a potential limitation in that participants were more likely to be connected to statewide professional networks than to represent the full range of rural science education leaders, including those who were most isolated and least networked, and who may have had the most acute experiences of the barriers this study sought to examine.

The intensive and compressed work schedules of rural educational leaders introduced an additional logistical limitation that shaped the timing of data collection. Given the multiple hat demands of rural science education leadership (Copeland, 2013) and the limited discretionary time available to participants during the active TK–12 school year, interviews were strategically scheduled between November 2025 and February 2026, a period that encompassed several school vacation windows.

**Summary**

This chapter describes the methodological foundation upon which this study was built, establishing the epistemological, procedural, and ethical commitments that shaped how data were collected, analyzed, and interpreted. The chapter opens with a restatement of the study's central research purpose and an overview of its organizational structure before presenting the rationale for a qualitative, role-based case study design rooted in a transformative and postmodern interpretive framework. This philosophical orientation positions knowledge as co-constructed between researcher and participants, and foregrounds the researcher's own positionality as both a resource and a responsibility throughout the inquiry.

The chapter details the purposeful participant selection process, which draws on three tiers of rural science education leadership across California, from the most isolated Tier 1 counties to Tier 2 rural counties to statewide organizations, ensuring that the study's findings reflected the full spectrum of rural science education leadership conditions. The five essential job functions developed in collaboration with the CISC Science Subcommittee provided the functional criteria through which participants were identified and qualified, ensuring that all eleven participants brought substantive, role-based expertise to the study. Participant demographics are summarized and the use of tree-based pseudonyms is explained as both an ethical protection and a symbolic acknowledgment of the rural landscapes from which participants led.

Data collection procedures are described, including the use of snowball sampling, semi-structured online interviews conducted via Zoom, and a multi-round coding process combining thematic and in vivo approaches. The strategic scheduling of interviews between November 2025 and February 2026 is explained as a deliberate accommodation to the intensive and compressed work schedules of rural educational leaders (Copeland, 2013). Ethical considerations were addressed through the university IRB approval process, informed consent procedures, confidentiality protections, and ongoing researcher reflexivity. Trustworthiness was established through attention to credibility, dependability, confirmability, and transferability addressed respectively through the depth of the literature review, triangulation, peer review, consistent procedural application, reflexivity, and thick contextual description (Lincoln & Guba, 1985).

Taken together, the methodological decisions described in this chapter reflect a commitment to rigorous, justice-oriented inquiry that honored the complexity of rural science education leadership and center the lived experiences of the leaders most directly engaged in the work of increasing science education access for minoritized students. Chapter Four and Chapter

Five present the findings that emerged from participant interviews, findings that, as the methodology of this study is designed to surface, illuminate not only what rural science education leaders navigated but how, and to what end.

## Chapter Four: Findings — Systemic Barriers in Aligning NGSS Instructional Practices to the Needs of Minoritized Students

### Introduction

This chapter presents the findings that emerged from semi-structured interviews conducted with eleven rural science education leaders across California between November 2025 and February 2026. The findings are organized in response to Research Question One: *What systemic barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?*

The participants in this study represented three tiers of rural California science education leadership, Tier 1 county leaders serving California's most rural and under-resourced communities, Tier 2 county leaders serving rural communities across a broader geographic range, and Tier 3 statewide leaders whose work connected local rural contexts to California's broader science education infrastructure. Together these eleven leaders brought a combined depth of experience in rural science education leadership that spanned classroom teaching, county office administration, university-based professional learning, and statewide policy and curriculum work. Their accounts of the barriers facing rural science education were not theoretical, they were lived, specific, and documented with the precision of leaders who had spent careers navigating the structural conditions they described.

A note on the sequencing of the research questions in this study is warranted before the findings are presented. Research Question One - addressing systemic and cultural/historical barriers, is presented first not because it is more important than Research Question Two but because the interview design itself reflected this sequencing logic. The semi-structured interview protocol was organized as a mini retrospective, moving participants through a reflective arc that began with their observations about student science performance, moved through their identification of the barriers and challenges their students and systems faced, and arrived, only after that reflective groundwork had been laid, at the navigational strategies and successes they had developed in response. This sequencing was deliberate. Participants needed the opportunity to name, examine, and sit with the barriers before they could fully articulate how they had navigated them. The retrospective quality of the interview format created the conditions in which barriers could be discussed not as abstract policy problems but as the specific, lived, structural conditions that participants had spent their careers working within and against.

Throughout this chapter, participant voices are centered as the primary source of knowledge. Participants are identified by their tree-based pseudonyms as described in Chapter Three. The findings are organized into three sections. Section One presents findings addressing systemic barriers. Section Two presents findings addressing cultural and historical barriers. Section Three presents a synthesis of the three interdomain themes, distinct geospatial challenges, distinct resource navigation, and distinct relational dynamics, that emerged across all three domains of literature and across all eleven participant accounts, with participant percentages documenting the prevalence of each theme across the sample. Each section opens with an overview of the finding, followed by an integration of participant voices that together build the evidentiary case for each claim.

*RQ1-What system barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?*

*RQ2-How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?*

**Table 3**
*Emergent Findings and Sub Findings*

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| **Systemic Barriers** | Finding 1.0 | System constraints on rural leaders' support of science education |
| | Finding 1.1 | De-prioritization of science in rural education through lack of accountability |
| | Finding 1.2 | Economics of scale in rural educational systems |
| | Finding 1.3 | Limited rural teacher capacity building in science content and pedagogy |
| **Cultural and Historical Barriers** | Finding 2.0 | Limited rural educator cultural competence with minoritized/marginalized students |
| | Finding 2.1 | Historical challenges to science instruction for the rural school |
| | Finding 2.2 | Social and/or professional class divide amongst communities |
| **Navigation to increase access** | Finding 3.0 | Brokering science access for marginalized students |
| | Finding 3.1 | Place-based science leadership/ instruction to provide science instruction support |

The geospatial challenges documented in this study were among the most pervasive findings across the full participant sample. Ten of eleven participants, 91% of the rural science education leaders interviewed described at least one dimension of geospatial challenge as shaping the conditions under which they worked to support science education for minoritized students. The three dimensions of geospatial challenge that emerged across participant accounts were geographic isolation, infrastructure gaps, and professional isolation and they operated not as discrete barriers but as mutually reinforcing conditions that compounded one another in ways that made equitable science education structurally difficult to sustain. Geographic isolation was documented by 64% of participants, manifesting in accounts of schools separated from district offices by mountain passes and hours of driving, communities accessible only by snowmobile in winter months, and students whose closest medical provider required crossing state lines. Infrastructure gaps were documented by 45% of participants, surfacing in accounts of schools without reliable internet access, communities without grocery stores or medical facilities, transportation systems consuming over 500 hours of staff time per week, and districts on the verge of eliminating bus service entirely. Professional isolation was the most consistently documented dimension, referenced by 73% of participants, appearing in accounts of teachers with zero access to professional learning, singleton science teachers with no peers to collaborate with, districts that had purchased curriculum years earlier that remained unopened on shelves, and counties where science had not been meaningfully taught at the elementary level for over a decade despite repeated efforts to address the gap. Together, these three dimensions of geospatial challenge constituted what this study identifies as the distinct geospatial terrain of rural science education leadership a terrain that shaped not only what was logistically possible but what was professionally sustainable, relationally supportable, and structurally equitable for the minoritized students whose science education depended on leaders navigating it every day.

The distinct resource navigation demands facing rural STEM leaders were documented across four interconnected components that together revealed the depth and breadth of the resource challenge in rural science education. The need for professional learning in science and the professional learning demands of NGSS implementation were the most universally documented components referenced by all eleven participants, representing 100% of the study's rural science education leaders. Without exception, every participant described a professional learning landscape that was structurally inadequate to the demands of NGSS implementation, whether through the absence of access, the absence of time, the absence of funding, or the absence of the sustained instructional coaching that three-dimensional science learning required. The inconsistent implementation of science instructional materials was documented by 73% of participants, eight of eleven, surfacing in accounts of curriculum adoptions that sat unopened on shelves, supplemental resources that had become substitutes for rigorous instruction, and districts where the materials designated for science instruction on a SARC report bore no relationship to what was actually happening in classrooms. Multi-role expectations and the many hats phenomenon were documented by 64% of participants, seven of eleven, with rural science education leaders describing the compression of curriculum development, professional learning facilitation, grant reporting, community partnership management, data coordination, and in some cases classroom teaching and school site administration into single roles that in more resourced systems would have been distributed across many individuals. The question of scale and the structural mismatch between the tools, policies, and funding mechanisms designed for larger systems and the realities of the smallest rural districts was documented by 73% of participants, eight of eleven, surfacing in accounts of reporting requirements designed for large multi-agency systems being applied to single-staff county offices, community schools funding denied to districts too small to meet minimum enrollment thresholds, and data tools requiring a minimum of eleven students to generate disaggregated results in counties where some entire school districts enrolled fewer students than that threshold. Together, these four components painted a portrait of resource navigation that was not incidental to rural science education leadership but constitutive of it, a persistent, structural, and compounding set of demands that shaped what was possible, what was sustainable, and what remained perpetually out of reach for the leaders and the students this study sought to illuminate.

The distinct relational dynamics of rural STEM leadership were documented across six interconnected categories that together illuminated the social, political, and community-based conditions within which rural science education leaders worked to support minoritized students. Rural community expectations and multigenerational dynamics were referenced by 64% of participants, seven of eleven, surfacing in accounts of boarding school trauma still fresh in the memories of living community members, nine overdose deaths on a reservation rippling through an entire school community simultaneously, multigenerational Washoe families whose distrust of government institutions was rooted in experiences within living memory rather than distant history, and communities where the families of students had lived on the same land for generations in ways that shaped every dimension of their relationship to the school. Rural politics were documented by 55% of participants, six of eleven, appearing in accounts of six months of science policy debate driven by the intersection of science education and religious belief, unwritten district practices contravening state law because no administrator would put the community backlash in writing, a political landscape described by one participant as not just rural but red, and Hispanic students and families experiencing such acute political vulnerability that their school had installed opaque slats in its fences to shield them from the street. The social and professional class divide emerged as the most consistently documented relational category, referenced by 82% of participants, nine of eleven, surfacing in accounts of post-COVID demographic shifts restructuring rural mountain communities along class lines, tracking systems sorting students into remedial and college preparatory science pathways on the basis of identity rather than capacity, ranch-owning families whose children dominated the science fair while the children of tulip farm and dairy workers went without speaking or listening opportunities in their science classrooms, and communities losing their trailer parks and with them, their socioeconomic diversity, to the influx of wealthier newcomers seeking rural quality of life.

Marginalization due to language barriers was documented by 55% of participants, six of eleven, appearing in accounts of multilingual learners whose deep ecological knowledge was systematically unengaged in science classrooms, students who went entire school days without a single speaking or listening opportunity in science, a student whose Mixteco-language explanatory model for preventing mosquito bites was dismissed by a teacher who lacked the tools to recognize its scientific sophistication, and districts that appeared to be actively avoiding the acknowledgment that they had English learners with specific instructional needs that were not being met. Marginalization across contents and systems was documented by 64% of participants, seven of eleven, surfacing in accounts of students pulled out of science for designated ELD services during the only science block on the master schedule, Native American students over-identified for special education at rates that reflected institutional bias rather than assessed need, students in eighth grade reading at a third grade level because they had never had a credentialed teacher, and students who had been removed from every science class and every field trip they had ever been assigned to until a juvenile hall teacher gave them their first real science experience. Local partnerships emerged alongside the professional learning finding as the second universally documented category, referenced by all eleven participants, representing 100% of the study's rural science education leaders. Without exception, every participant described community partnerships not as supplemental enrichment but as structural necessity, the organizational infrastructure through which rural science education leaders built the professional learning, the curricular resources, and the science access opportunities that their systems could not otherwise provide. From the thirty-year NGO network of Incense Cedar to the STEM Expo redesign of Ginkgo, from the Washoe Cultural Department partnerships of Redwood to the statewide NGSS Collaborative infrastructure of Lemon Tree, local partnerships were the connective tissue through which rural science education leadership became possible — and the most powerful evidence in this study that relational trust, built over time in specific places with specific communities, was not merely a feature of rural educational leadership but its foundation.

## Systemic Barriers to Rural Science Education Leadership

### *Finding 1.0 - System Constraints on Rural Leaders' Support of Science Education*

There were systemic barriers to science access for minoritized students that rural science leaders described, ranging from state-level constraints to individual educator capacity. These systemic barriers impacted the daily work of science education.

The overarching systemic context within which rural science education leaders operated was one of structural compression, resource scarcity, and policy misalignment. Across all eleven participants, a consistent picture emerged of leaders working within systems that were not designed with rural contexts in mind, systems that assumed levels of staffing, infrastructure, funding, and specialization that rural districts and county offices simply did not possess. The cumulative effect of these structural conditions was that rural science education leaders spent a disproportionate share of their professional energy adapting, translating, and working around systems rather than leading within them.

The majority of participants described these structural conditions in vivid and concrete terms. Pine captured the translational burden placed on rural leaders with striking clarity:

> We sometimes joke that we get handed San Diego, Sacramento, Orange County stew, right? And have to figure out how to turn it into lasagna. And I understand why it happens, I especially having the context of working in Los Angeles, like I get it but I do think that there's such a large part of academic leadership in rural county offices that really is just okay, here's this amazing framework, or here's this incredible shift in pedagogy, now how the heck are we going to pull it off with the funding and the staffing and all the things? (Pine)

Redwood described the structural compression of rural leadership with equal directness, naming the specific and exhausting reality of a single individual responsible for the full scope of a county office and school district simultaneously:

> I am all of the curriculum and programs, all of the data and test coordinating and professional development, and all of the grants, applying, reporting, implementing, making sure we're in compliance, and all the community partnerships. And now I'm the Principal at one of the schools. (Redwood)

Lemon Tree, operating at the statewide level through the California NGSS Collaborative, described the structural reality from the opposite vantage point.Lemon Tree worked to create professional learning infrastructure that could reach rural settings that lacked both the funding and the personnel to do the work independently, noting that rural settings simply did not have the people to do the work that needed to be done for science. Oak described the arithmetic of this constraint in Siskiyou County, 26 to 28 independent districts serving a total of 5,600 students, many in schools so small that a district of 20 students was not unusual, and for those schools the disaggregated data that would allow leaders to understand and respond to equity gaps simply did not exist. Magnolia framed the structural constraint at the state level, identifying the way California's compensation model for science education, funding only two high school science courses, embedded underfunding directly into the architecture of the system. Ginkgo described a county where science performance sat at 19.85% met or exceeded on the CAST,  the lowest of all three tested content areas, in a community where the structural conditions producing that outcome had been documented and discussed for over a decade without producing systemic change. And Incense Cedar, with thirty years of rural science education leadership in Plumas County, described a district on the verge of sunsetting bus transportation due to budget cuts, a loss that would directly compromise the place-based field science instruction that was the cornerstone of the county's science education program.

Together, these accounts illuminated a system in which the structural conditions of rurality, compressed leadership, resource scarcity, geographic isolation, and policy misalignment, operated not as isolated challenges but as a mutually reinforcing set of constraints that shaped every dimension of rural science education leadership. The participants in this study were working to build equitable science education within conditions that made coherence structurally difficult to achieve and sustain.

### *Finding 1.1  De-prioritization of Science in Rural Education Through Lack of Accountability*

The ways in which science education was neither centered nor uplifted created an impactful barrier for rural science education leaders searching for ways to message the importance of science education.

Among the most consistent and consequential findings of this study was the degree to which science education was systematically deprioritized in rural educational settings, not through deliberate neglect but through the absence of accountability structures that would have required districts and county offices to attend to science as urgently as they attended to English language arts and mathematics. This finding was documented across seven of eleven participants and was grounded in three interconnected mechanisms: the structure of the California school dashboard, the restrictions placed on state professional learning funding, and the political dynamics at the board and community level that further displaced science from the center of rural educational attention.

The California school dashboard emerged across multiple participant accounts as the primary structural driver of science de-prioritization. Lemon Tree described the mechanism with precision, because science appeared on the dashboard for informational purposes only, rather than as a metric that could place a district in differentiated assistance, districts faced no institutional consequence for science underperformance. The result was that even districts that recognized a science gap would pour their money and resources into English language arts and mathematics because those were the measures that shaped public perception of school quality. Oak named the consequence directly: "Science is not on the forefront of their mind, and especially since it's not included for DA criteria, it's like, cool. Thank you. One less thing to worry about."

Magnolia surfaced an additional and deeply troubling dimension of this finding at the state policy level. California's professional learning block grants, substantial funding provided to districts annually, were restricted in ways that explicitly excluded science professional learning. As Magnolia described it, districts were returning significant amounts of unspent funding to the state each year while simultaneously lacking the resources to support science instruction, because those funds could not legally be applied to science:

> "Every year, you can download how much money every district requested or has been given and how much money the district is returning to the state, and it's a lot, it's really a lot, but those funding, God forbid that we are going to use it for science. I personally also hold CDE accountable, because there's nobody at CDE that is a strong advocate for expanding those funding, because when year after year you see that you have extra money, you should suggest the legislation, what about if they can use it for science?" (Magnolia)

Ginkgo named the elementary science de-prioritization with a directness rooted in over a decade of witnessing the same pattern repeat without resolution:

> "Science is just not being taught and that's still, that is, I would say, the number one issue we have here. Science is not being taught at the elementary level the way it should be. We've talked about the elementary problem for a decade now, it's not getting taught, it's not getting taught, it's not getting taught. And what have we done?" (Ginkgo)

Redwood described a parallel dynamic in Alpine County, where the focus on ELA had consumed the available leadership bandwidth to such a degree that science had not been a meaningful instructional priority, with the county's science work centered primarily on engagement rather than rigorous instructional improvement. Valley Oak documented how rural districts had used COVID relief funds for large-scale curriculum adoptions without accompanying teacher training, producing a situation in which the investment in materials was not matched by investment in the human capacity to use them, and in which being unprepared to teach NGSS had become an acceptable answer in rural communities at a scale that would not be tolerated elsewhere. Douglas Fir described a county where science was simply not often a huge focus in terms of professional development, a normalization of science absence that had produced teachers who arrived in the Science Leadership Exchange having avoided teaching science for years without institutional consequence.

Taken together, the evidence for Finding 1.1 painted a picture of science de-prioritization that was not the result of individual failure or indifference but of systemic design, accountability structures that exempted science from consequence, funding mechanisms that withheld professional learning resources from science, and professional norms of rural education that had, over time, accommodated these conditions by treating science as optional rather than essential. The de-prioritization of science in rural education was ordinary, unremarkable, and deeply consequential for the minoritized students who deserved it most.

### ***Finding 1.2 - Economics of Scale in Rural Educational Systems***

The economies of scale in rural education systems referred to the small numbers of students and staff available to implement functioning science education systems.  Many examples described rural science education leaders as having to take note of their lack of numbers when making science implementation decisions.

The economic conditions of rural educational systems created a set of structural barriers to equitable science education that operated independently of leadership intent and that could not be resolved through will, creativity, or commitment alone. Across participants, the economics of scale in rural education manifested in three primary dimensions: the compression of human capital, the inadequacy of fiscal resources, and the geographic constraints that compounded both.

The compression of human capital was among the most consistently documented features of rural educational economics across participants. Oak described Siskiyou County's 26 to 28 independent districts serving 5,600 total students, a ratio that produced schools so small that a district of 20 students or less was not unusual and in which the disaggregated data needed to identify and address equity gaps simply could not be generated. Within these micro-districts, Happy Camp Elementary stood as a particularly stark illustration of what the economics of scale produced at the classroom level, students in sixth through eighth grade who had never been taught by a credentialed teacher, whose entire instructional histories had been shaped by teachers on provisional intern credentials placed in multi-grade classrooms because no credentialed teachers were available or willing to serve in communities so remote and under-resourced:

> "In terms of equity and access, it breaks your heart, because those students are not going to be having any access to eighth grade materials or even sixth or seventh." (Oak)

Redwood described the economic conditions of rurality at their most extreme in Alpine County, where the entire county served only 67 students across a geography divided by a mountain range that made one end of the county a four-hour drive from the other when the mountain pass was closed in winter. The structural consequences of this geography were not merely logistical, they were equity consequences, producing conditions in which the students most in need of educational support were also the students most structurally difficult to reach:

> "We applied for implementation funds, and they're like, you're not big enough. Well, okay. And I understand that. But if their school is not providing them with a therapist, there are referral services that they can go out and get those services, and here we don't have that. So when you say we're not big enough that it won't affect enough people, people wise, you're right, but percentage wise, you've just denied services to 100% of the population of this county." (Redwood)

Pine documented the economic conditions of rurality at their most extreme in North County Mariposa, where a community had lost its only grocery store and its only doctor in the same fire, a school community where students arrived without access to basic nutrition, where food banks had to be established at the school site to meet survival needs before instructional needs could even be addressed, and where the road connecting the community to the district office was nearly two hours long and at times impassable. Ginkgo described a county where the single credentialed physics teacher in the entire county lived in the neighboring city of Chico and was expected to leave, a human capital fragility that illustrated how the economics of rural teacher recruitment and retention produced science education conditions that were perpetually one resignation away from collapse. Incense Cedar described a district facing the imminent elimination of bus transportation due to budget cuts, a loss that would directly compromise the place-based field science instruction that had defined the county's science education program for thirty years. Magnolia named the systemic dimension of this constraint at the state level:

> The CAST (California Science Test) is asking the students to be proficient in biology, chemistry, physics, and earth science when the vast majority of our students

> in California have the opportunity to take only two courses. So there you go, 50% of the answer will not be correct, and not because of the student, but it's because the high school system is providing them only two courses. (Magnolia)

Douglas Fir described the economics of special education in Trinity County, a county in which the scarcity of credentialed special education teachers had produced caseloads so large that a county-level waiver had been required to accommodate them, with up to 35% of students in some classrooms carrying IEPs or 504s and with the only special education teacher serving the entire district. Torrey Pine documented the economics of professional learning access in the rural and tribal communities of Arizona and San Diego County, where teachers had zero access to professional learning and drove through snowstorms to attend a workshop, their gratitude so profound that it constituted evidence not of exceptional generosity but of the depth of the structural deprivation that made any provision of professional learning feel extraordinary rather than ordinary. Juniper described the geographic economics of Humboldt County's rural science education landscape, schools on Karuk ancestral land, on the Hoopa reservation, on Yurok ancestral land, communities separated by hours of driving across some of the most geographically isolated terrain in California, where the distance between schools was itself a structural barrier to the collaboration and professional community that science education reform required. These concerns were echoed by the majority of the participants in this study.

***Finding 1.3 - Limited Rural Teacher Capacity Building in Science Content and Pedagogy***

Educator capacity for both the content and pedagogical moves of a classroom environment impact student success. The capacity of rural teachers to deliver high-quality, culturally responsive, NGSS-aligned science instruction emerged as one of the most pervasive and consequential barriers documented in this study. Across nine of eleven participants, limited teacher capacity in science content and pedagogy was identified not as a peripheral concern but as a central structural condition that shaped what was possible in rural science classrooms. The causes of this capacity deficit were multiple and mutually reinforcing: inadequate access to professional learning, the normalization of science avoidance in elementary teaching culture, the multi-subject demands placed on rural teachers, and the absence of sustained instructional coaching and support structures in most rural systems.

The prevalence and cultural acceptability of science avoidance among rural elementary teachers was documented with remarkable candor across multiple participant accounts. Douglas Fir described a third through fifth grade teacher who disclosed in the context of the Science Leadership Exchange:

> "I'll be completely honest. I hate teaching science. It scares me. I just feel like I don't know enough, and I probably avoid it. I don't know how much they really get from me. And that's third, fourth and fifth grade." (Douglas Fir)

Pine described a parallel dynamic where the ease and accessibility of Mystery Science had become a substitute for rigorous science instruction not because teachers lacked care for their students but because they lacked time, support, and the pedagogical confidence to move beyond it:

> Nobody, no teacher is showing up going, oh, I'm going to take the low hanging fruit because I don't care about kids. They're pulling the low hanging fruit because they don't have the time, they don't have the support. They're building their own capacity in these specific areas. (Pine)

Lemon Tree articulated the distinction between content mastery and pedagogical mastery that the existing professional learning system had failed to make:

> When we think about the people who are leading science in rural settings, they are often not people who themselves have a strong science identity. So supporting them to feel like they know what science is, to feel like they have mastery of that they don't need full content mastery, they need pedagogical mastery. (Lemon Tree)

Torrey Pine documented the professional learning access gap at its most extreme, teachers who had zero professional learning and who drove through snowstorms to attend a workshop, their gratitude evidence of the depth of the professional isolation that rural science teachers experienced. Ginkgo named the temporal dimension of the capacity deficit. In Ginko's county, constant teaching about the basics of NGSS had never stopped, teachers would still call them new standards in year twenty of implementation, and the high turnover rate meant that the work of building NGSS understanding was perpetually beginning again. Oak described a first-grade teacher in her eighth year of teaching who had never taught science and had developed instructional habits that made the idea of learning targets seem unimportant, a portrait of what happened when the absence of sustained capacity building over years produced not only a skills gap but a mindset gap that was far harder to close. Redwood described the CAL-MSCS grant opportunity that Alpine County had been unable to fully utilize, not because the funds were insufficient but because there was only one person to do the implementing, the reporting, and the compliance work, and that person was also the principal of one of the schools and the grant reporter for two separate agencies simultaneously. Magnolia described the frustration of arriving at rural districts where the professional development request was simply 'come on this day and do these topics,' a transactional model of professional learning that bore no relationship to the sustained, relationship-based capacity building that NGSS implementation required. Valley Oak named the cultural acceptability of science unpreparedness in rural contexts, the fact that being unprepared to teach NGSS had become an acceptable answer in rural communities at a scale that was not acceptable elsewhere, as itself a form of structural inequity, a differential standard applied to rural science education that had allowed the capacity deficit to persist without institutional consequence or systemic response. Incense Cedar documented the scale of the teacher preparation challenge with specificity: only 15% of elementary school teachers had a science degree, meaning that most teachers had effectively avoided the science bullet in their undergraduate preparation and arrived in rural classrooms with a single science education course as their entire preparation for teaching the three-dimensional, inquiry-based, culturally responsive science instruction that the NGSS demanded.

## Cultural and Historical Barriers to Rural Science Education

### *Finding 2.0 Limited Rural Educator Cultural Competence with Minoritized/Marginalized Students*

Cultural competence, or the ability to see nondominant cultures as having assets, remained elusive to educator practice in science. The cultural competence of rural educators, their capacity to recognize, affirm, and build upon the cultural identities, funds of knowledge, and ways of knowing that minoritized students brought to science learning, emerged as a significant and pervasive barrier across participant accounts. This finding was not simply about the absence of culturally responsive teaching strategies, though that absence was consistently documented. It was about something more foundational: the persistence of deficit-oriented beliefs about the capacity of minoritized students that shaped how teachers saw their students, how they designed instruction, and how they interpreted student engagement and performance.

Juniper named the deficit thinking barrier with a directness and clarity that no scholarly framing could match:

> The biggest challenge is mindset and beliefs. It always is. Teacher and leader beliefs about the quote unquote capability of students who are black, brown, native, special ed, foster youth, low socioeconomic status. They talk a good talk, and they say, oh, I believe all students can learn. But when you have a discussion with them about why a student is struggling, as soon as you start talking about individual students, it comes to their beliefs about that kid, or their family. Those kids or these kids, they don't have this, they don't have that. It's this deficit mindset that people say they don't hold, but they do. (Juniper)

Magnolia surfaced the cultural competence gap through the story of Alina, a student whose Mixteco-language explanatory model for preventing mosquito bites had been dismissed by a teacher who lacked the tools to recognize its scientific sophistication. In the professional learning context, the teacher eventually recognized the brilliance in Alina's response but only after a facilitated process of decoding what Alina had communicated through a multimodal model that the teacher's assessment framework had no capacity to see. Magnolia's framing of the broader epistemological failure was among the most memorable in the study:

> The students are not cookies. They are beautiful croissants. And some are chocolate croissants, you know. Or pan dulce — they could be a lot of things. So it's, what I think might be missing from these student data in science performance is the range of brilliance that we can say, oh yeah, this is a very strong performance for the student. (Magnolia)

Lemon Tree identified language as a central dimension of the cultural competence gap:

> "Teachers knowing how to have science conversation done in home language and home words, whether that's Spanish or whether that's just not academic English, being comfortable with the science. The kids don't have to say density. They can talk about what they know, and they can talk about what they understand in a way that makes sense, and then layering on the vocabulary. We still have teachers who are really struggling with how do you do that? And that sort of disenfranchises some kiddos off the bat from participating in their science education and realizing how much they do understand and want to bring to the table." (Lemon Tree)

Ginkgo documented the cultural competence gap through the multilingual learner shadowing work in Glenn County, describing a physics teacher who was genuinely skilled in NGSS inquiry-based instruction but whose differential engagement with English learner students, lowering expectations, focusing on apparatus setup rather than deeper conceptual questions, moving toward the high-performing groups and away from the EL-majority groups, produced conditions in which entire school days passed without a single speaking or listening opportunity for some of the most linguistically marginalized students in the class. Valley Oak named the cultural competence gap from the professional learning design perspective, describing teachers who made assumptions about their students' capacity that were not necessarily true, and who in doing so created the conditions that confirmed those assumptions, leaving the deep ecological knowledge of rural multilingual learners systematically unengaged in science classrooms designed for a different kind of knowing. Redwood described the cultural competence gap in Alpine County through the lens of institutional bias, the over-identification of Native American students in special education, the dress code violations written up selectively along racial lines, the suspension patterns that reflected institutional assumptions about which students were capable of meeting behavioral expectations rather than assessments of what students actually needed. Incense Cedar offered a counter-example that illuminated what cultural competence in rural science leadership looked like when deliberately cultivated:

> One thing I learned from a professor of mine at Cal was, you either map yourself or someone else will map you. And if someone else maps you, they may label you, name you, put you in a legend and change your whole identity. And so we do a lot of map making because it's identity stuff, and every child can claim their own identity through the maps they make. (Incense Cedar)

Pine named the cultural competence gap in the specific context of Mariposa County's science curriculum, acknowledging directly that the district had not made enough of a focused effort to ensure that their science curriculum was culturally responsive to the Native American communities whose epistemological relationships to the land represented a profound and largely untapped resource for science learning. Torrey Pine documented the cultural competence gap in rural tribal communities where the educators were not from those communities at all, a structural condition of rural teacher recruitment that produced classrooms where the cultural distance between teacher and student was not only significant but largely unacknowledged and unaddressed.

### *Finding 2.1 Historical Challenges to Science Instruction for Rural Schools*

Invisible, and yet very powerful, challenges to science instruction were evident for rural science leaders who understood the pre-existing or historical context of their locations. The historical conditions that had shaped science instruction in rural California often were not background context for the barriers participants described, they were the barriers themselves, operating across generations in ways that had produced the present-day conditions of inequity that this study sought to document. Many participants described a rural educational landscape marked by colonial legacies, political polarization, systemic exclusion, and the long history of rural communities being served by, and learning to distrust, institutions that had not been designed with their needs in mind.

Juniper provided the most historically grounded and personally direct account of this finding:

> There's traditionally cultural trauma from boarding schools, things like that. There's resistance to all sorts of things in schools based on your grandparents and your parents. School itself is this limited thing that was made for white children, right, or for Native children to be assimilated. (Juniper)

Redwood deepened this historical account with a specificity that brought the boarding school legacy out of the abstract and into the living present:

> The Stewart school here in Carson, which was where a lot of Washoe were sent, closed in 1980, which means that most of our kids have an adult in their lives who went to the Stewart school. For some of the older people, it was something where we used to hide from the people who would come and take us to the school, and then they would make us go if they found us. So yeah, that's why that distrust kind of still exists for our government organizations, because it's still fresh in people's minds. (Redwood)

Redwood also documented the living weight of community trauma in Alpine County through the account of nine overdose deaths on the reservation between March and September of a single year. This community loss was so concentrated and so total that multiple children simultaneously lost mothers, sisters, cousins, and aunts. The school's response had to begin not with science instruction, but with the basic work of helping staff understand why children were not coming to school and what it would take to create the conditions in which coming to school felt safe enough to sustain.

Douglas Fir documented the political dimension of historical challenge in Trinity County, describing a conservative community context in which book challenges, resistance to LGBTQ inclusion, and the political polarization of once-neutral educational content had created conditions in which unspoken district practices directly contravened state and federal law:

> "It's the climate of the area. No one's going to put it in writing, but this is what they're doing." (Douglas Fir)

Pine described the politicization of science education in Mariposa County as a more recent intensification of a tension that had always been present, the longstanding intersection of science education and religious belief becoming newly charged in a national political climate that had eroded the sense of public schools as neutral civic spaces:

> "Things that I think used to just feel very neutral no longer do. I think there used to be a sense of there are these neutral spaces, like public schools, and outside of those neutral spaces, we are going to teach our children what we believe. And what I'm seeing a shift in from all sides is that it's the public school's responsibility to be supporting the parents' beliefs, boards and teachers and principals in this really, really sticky spot." (Pine)

Incense Cedar named the colonial dimensions of historical challenge with characteristic depth and candor:

> We're not just rural. We're red politically. So when you look at the politics of California and where the money goes and where the power is, it's not up here, even though the ecosystem services of forest and timber and water and all of that are up here. There is a natural, even unconscious and maybe not even intentional at times, marginalizing of just being rural. (Incense Cedar)

Lemon Tree documented the present-day manifestation of historical challenge through an image that brought political marginalization into the physical architecture of school spaces, a school that had installed opaque slats in its chain-link fences to protect Hispanic students and families whose fear of visibility in the current political climate had made their presence in a public institution feel unsafe. Magnolia described the historical entrenchment of tracking systems, English Language Development (ELD) pullout policies that dated to 2010 and continued to create conflict for science instruction, and the structural barriers embedded in high school course progression systems that had excluded Latino and Black students from the science pathway required for college eligibility since the earliest grades.

Ginkgo described a county where the word *equity* could not be used in some neighboring counties, where the political climate had made the language of equity itself a marker of ideological conflict rather than a shared educational commitment and where the challenge of addressing differential equity impacts for marginalized students required navigating a political landscape in which many administrators simply did not see that equity gaps existed.

Juniper described the school that had been sued by the NAACP and the ACLU twice for its treatment of Native American students, a present-day legal record that was not a historical artifact but an active institutional condition, the most recent expression of a pattern of institutional discrimination that had produced the intergenerational community distrust documented throughout this finding.

***Finding 2.2 -Social and/or Professional Class Divide Among Communities***

With fewer community members, on average, rural locations more acutely felt the class, social, and knowledge divides present in every community. The social and professional class dynamics of rural communities constituted a barrier to equitable science education that operated both between communities and within them, shaping which students were perceived as capable, which were tracked into lower academic pathways, whose funds of knowledge were recognized and honored in science classrooms, and whose relationship to the natural world was treated as a resource for science learning rather than a deficit to be overcome.

Valley Oak described the post-COVID class dynamics of Nevada County with particular clarity:

> Now it is like the haves and the ones who work for them. And so in the classrooms, those students are all going to the same elementary schools, especially, there is a great divide in which funds of knowledge are being brought forward in the classroom versus which students' funds of knowledge are really not being honored. And that's really evident because of the socioeconomic divide. (Valley Oak)

Juniper described the class divide in Humboldt County through the lens of tracking systems that had structured access to science education along lines of race and class simultaneously:

> I taught them both. And I can just illustrate it with a quick story. I had two Native American twin girls who were in the foster care system, and they were in my quote unquote remedial class. And I went to the counselor and said, why are they in this class, they need to be in my prep class. This is ridiculous. And she said they're Native American in the foster care system, like that explained everything. (Juniper)

Ginkgo documented the class divide in Glenn County through the specific and illuminating contrast between the science fair experience of a student whose family owned a 300-acre ranch with horses, whose horse experiment produced genuinely excellent science and the English learner student whose scientific thinking was systematically unengaged and whose participation in the science fair had historically been structurally discouraged by the exclusive, quality-first model that Ginkgo had inherited and worked to dismantle. Redwood described the class divide in Alpine County through the specific marginalization of American Indian students who were simultaneously the numerical majority of the school population and the most consistently marginalized population in terms of outcomes, institutional bias, and over-identification in special education, a dynamic that illustrated with particular force the distinction between being a minority and being minoritized. Pine named the class dimension of the science access gap in Mariposa County through the example of the agricultural department pathway, a program that engaged the vast majority of students but that was a very White pathway in a county where Hispanic and Native American students represented a significant and growing portion of the student population. Oak described the stark contrast between the science performance of Mount Shasta's more affluent families and the students of Yreka whose home prices were half as much and whose science outcomes reflected the difference. Lemon Tree described the intersection of race, class, and language in the marginalization of Hispanic students, noting that Hispanic students were definitely not a minority in many rural California communities but were definitively marginalized, their marginalization operating through class-based mechanisms of course tracking, absenteeism, suspension, and restricted access to AP and dual enrollment science pathways. Magnolia documented the class dimension of the science access gap at the most systemic level, the finding that Big Bear Unified, a predominantly White rural district, exhibited the same science performance gaps as Jurupa Valley, a 78% Latino district, a cross-district comparison that revealed how the mechanisms producing those gaps were not about race or ethnicity in isolation but about the intersection of race, class, language, and institutional structure. Incense Cedar named the class divide in Plumas County through the increasingly urgent dynamic of displacement:

> The more people who love the postcardness of where we live and move up here and pay cash for a home, it just puts more people in trailer parks, and we're losing trailer parks. So when you lose trailer parks, you lose, to us, the diversity. One of the core diversity lines in our community. (Incense Cedar)

The influx of wealthier newcomers seeking the natural beauty and quality of life that rural California communities offered had accelerated dramatically in the post-COVID period, and what Incense Cedar added to this picture was the temporal dimension, the recognition that this was not a stable condition but a worsening one, that the diversity being lost was not an abstraction but a living, specific, and increasingly threatened condition of the rural educational landscape, one that the science education system had not adequately honored when it was present and would not be able to recover when it was gone. The class divide in rural science education was not only a condition of classrooms. It was a condition of communities, and the forces producing it were accelerating in ways that rural science education leaders could document but could not, without structural intervention, reverse.

**Synthesis of Interdomain Themes**

The findings presented in Sections One and Two addressed the systemic and cultural/historical barriers to equitable rural science education documented in response to Research Question One. Before the chapter summary, it is important to note that these findings did not emerge from within a single domain of literature or a single type of barrier. They rose to the top across all three domains, rural educational leadership, science implementation, and the needs of minoritized students, making them interdomain concepts substantiated by the convergence of evidence across the literature and across all eleven participant accounts. Three overarching themes organized these findings: distinct geospatial challenges, distinct resource navigation, and distinct relational dynamics. The prevalence of each theme and its specific dimensions across the participant sample is documented here.

***Distinct Geospatial Challenges***

The geospatial challenges documented in this study were among the most pervasive findings across the full participant sample. Ten of eleven participants, 91% of the rural science education leaders interviewed, described at least one dimension of geospatial challenge as shaping the conditions under which they worked to support science education for minoritized students. The three dimensions of geospatial challenge that emerged across participant accounts were geographic isolation, infrastructure gaps, and professional isolation, and they operated not as discrete barriers but as mutually reinforcing conditions that compounded one another in ways that made equitable science education structurally difficult to sustain. Geographic isolation was documented by 64% of participants, seven of eleven, occurring in accounts of schools separated from district offices by mountain passes and hours of driving, communities accessible only by snowmobile in winter months, and students whose closest medical provider required crossing state lines. Infrastructure gaps were documented by 45% of participants, five of eleven, surfacing in accounts of schools without reliable internet access, communities without grocery stores or medical facilities, transportation systems consuming over 500 hours of staff time per week, and districts on the verge of eliminating bus service entirely. Professional isolation was the most consistently documented dimension, referenced by 73% of participants, eight of eleven, appearing in accounts of teachers with zero access to professional learning, singleton science teachers with no peers to collaborate with, districts that had purchased curriculum years earlier that remained unopened on shelves, and counties where science had not been meaningfully taught at the elementary level for over a decade despite repeated efforts to address the gap. Together, these three dimensions of geospatial challenge constituted the distinct geospatial terrain of rural science education leadership, a terrain that shaped not only what was logistically possible but what was professionally sustainable, relationally supportable, and structurally equitable for the minoritized students whose science education depended on leaders navigating it every day.

### *Distinct Resource Navigation*

The resource navigation challenges documented in this study were equally pervasive and equally compounding. Across the full participant sample, rural science education leaders described a persistent and structural pattern of resource scarcity that operated simultaneously at the financial, human, and temporal levels and that required leaders to invest extraordinary amounts of professional energy in the work of securing, translating, and sustaining resources that their urban and suburban counterparts could assume as baseline conditions. The four components of distinct resource navigation that emerged across participant accounts were the need for professional learning in science and the professional learning demands of NGSS implementation, the inconsistent implementation of science instructional materials, multi-role expectations and the many hats phenomenon, and the question of scale. The need for professional learning in science and the professional learning demands of NGSS implementation were the most universally documented components referenced by all eleven participants, representing 100% of the study's rural science education leaders. Without exception, every participant described a professional learning landscape that was structurally inadequate to the demands of NGSS implementation. The inconsistent implementation of science instructional materials was documented by 73% of participants, eight of eleven, surfacing in accounts of curriculum adoptions that sat unopened on shelves, supplemental resources that had become substitutes for rigorous instruction, and districts where the materials designated for science instruction on a SARC report bore no relationship to what was actually happening in classrooms. Multi-role expectations and the many hats phenomenon were documented by 64% of participants, seven of eleven, with rural science education leaders describing the compression of curriculum development, professional learning facilitation, grant reporting, community partnership management, data coordination, and in some cases classroom teaching and school site administration into single roles that in more resourced systems would have been distributed across many individuals. The question of scale was documented by 73% of participants, eight of eleven, surfacing in accounts of reporting requirements designed for large multi-agency systems being applied to single-staff county offices, community schools funding denied to districts too small to meet minimum enrollment thresholds, and data tools requiring a minimum of eleven students to generate disaggregated results in counties where some entire school districts enrolled fewer students than that threshold.

### *Distinct Relational Dynamics*

The distinct relational dynamics of rural STEM leadership were documented across six interconnected categories that together illuminated the social, political, and community-based conditions within which rural science education leaders worked to support minoritized students. Rural community expectations and multigenerational dynamics were referenced by 64% of participants, seven of eleven, surfacing in accounts of boarding school trauma still fresh in the memories of living community members, multigenerational Washoe families whose distrust of government institutions was rooted in experiences within living memory, and communities where the families of students had lived on the same land for generations in ways that shaped every dimension of their relationship to the school.

Rural politics were documented by 55% of participants, six of eleven, appearing in accounts of six months of science policy debate driven by the intersection of science education and religious belief, unwritten district practices contravening state law because no administrator would put the community backlash in writing, and a political landscape described by one participant as not just rural but red. The social and professional class divide emerged as the most consistently documented relational category, referenced by 82% of participants, nine of eleven, surfacing in accounts of post-COVID demographic shifts restructuring rural mountain communities along class lines, tracking systems sorting students into remedial and college preparatory science pathways on the basis of identity rather than capacity, and communities losing their trailer parks and with them their socioeconomic diversity to the influx of wealthier newcomers. Marginalization due to language barriers was documented by 55% of participants, six of eleven, appearing in accounts of multilingual learners whose deep ecological knowledge was systematically unengaged in science classrooms, students who went entire school days without a single speaking or listening opportunity in science, and districts that appeared to be actively avoiding the acknowledgment that they had English learners with specific instructional needs.

Marginalization across contents and systems was documented by 64% of participants, seven of eleven, surfacing in accounts of students pulled out of science for designated ELD services during the only science block on the master schedule, Native American students over-identified for special education at rates reflecting institutional bias, and students who had been removed from every science class and field trip they had ever been assigned to until a juvenile hall teacher gave them their first real science experience. Local partnerships were referenced by all eleven participants, 100% of the study's rural science education leaders, with every participant describing community partnerships not as supplemental enrichment but as structural necessity the organizational infrastructure through which rural science education leaders built the professional learning, the curricular resources, and the science access opportunities that their systems could not otherwise provide.

**Summary**

This chapter presented the findings of this study in response to Research Question One: *What systemic barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?* Seven findings were documented across two sections, addressing the systemic and cultural/historical barriers that rural science education leaders encountered in their efforts to support equitable science education for minoritized and marginalized students in rural California. Section One documented four systemic findings, the overarching system constraints that defined the structural context of rural science education leadership, the de-prioritization of science through the absence of meaningful accountability structures, the economics of scale that produced educational conditions in which equitable science instruction was structurally difficult to sustain, and the limited teacher capacity building that had produced a professional landscape in which science avoidance had become normalized and NGSS implementation remained perpetually beginning again. Section Two documented three cultural and historical findings, the limited cultural competence of rural educators with minoritized and marginalized students, the historical challenges to science instruction rooted in colonial legacies, political polarization, and the intergenerational distrust of educational institutions, and the social and professional class divides that shaped science access within rural communities along lines of race, language, and socioeconomic position. Section Three synthesized these findings across three interdomain themes, distinct geospatial challenges, distinct resource navigation, and distinct relational dynamics, documenting the prevalence of each theme and its specific dimensions across all eleven participants, with findings ranging from 45% to 100% participant representation across the individual components of each theme.

Taken together, these findings revealed a rural science education landscape in which the barriers to equitable science instruction were not the product of individual failure or local neglect but of institutional design, a design that had never fully intended to serve the students most consistently marginalized by rural science education and that continued to reproduce their exclusion through the ordinary, unremarkable operation of systems that looked neutral but were not. The findings of this chapter established the structural and cultural conditions against which the navigational strategies documented in Chapter Five must be understood, conditions that were real, compounding, and resistant to the incremental responses that the existing policy landscape had offered, and that demanded the structural transformation that Chapter Six will propose. Chapter Five presents the findings addressing Research Question Two, describing how rural science education leaders navigated these conditions in their efforts to increase science access for the students their systems were failing.

# Chapter Five: Findings — Rural Science Educational Leaders Navigating the Complexities of Supporting the Needs of Minoritized Students

## Introduction

This chapter presents the findings that address Research Question Two: *How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?* Whereas Chapter Four documents the systemic and cultural/historical conditions that make equitable rural science education structurally difficult, this chapter documents the conditions that make it possible: the creative, relational, and structurally responsive strategies that rural science education leaders developed in the spaces between policy intent and institutional reality, between what their systems provided and what their students deserved.

A note on the relationship between this chapter and the preceding one is warranted. The navigational strategies documented here did not emerge in a vacuum. They emerged directly from the structural conditions documented in Chapter Four, shaped by the geospatial challenges, the resource constraints, and the relational dynamics that defined the terrain within which these leaders worked. The interview design reflected this relationship deliberately. Participants moved through a reflective arc that began with the barriers, named them, sat with them, and only then arrived at the navigational strategies they had developed in response. The findings in this chapter must therefore be read in that sequence, not as solutions to the barriers documented in Chapter Four but as responses to them, enacted by leaders who understood the structural conditions they were working within and who refused, despite those conditions, to leave their students without access to the science education they deserved.

The navigational strategies documented in this chapter are organized through a macro, meso, and micro analytical lens. Strategies operating at the macro level addressed organizational and systemic conditions, the statewide infrastructures and regional networks through which rural science education leaders built collective capacity beyond what any single system could sustain alone. Strategies operating at the meso level addressed community partnership and district-wide leadership conditions, the local organizational innovations, creative resource arrangements, and sustained community relationships through which leaders engineered the structural conditions that made equitable science possible in their specific places. Strategies operating at the micro level addressed the instructional and relational conditions of science teaching and learning for individual students, the pedagogical practices, the place-based curriculum innovations, and the specific moments of student recognition and belonging that revealed what was possible when science instruction honored the full humanity of the students it was designed to serve.

Throughout this chapter, participant voices are centered as the primary source of knowledge. Participants are identified by their tree-based pseudonyms as described in Chapter Three. The findings are organized into two sections. Section One documents Finding 3.0 - Brokering Science Access for Marginalized Students, examining the macro and meso level strategies through which rural science education leaders created, sustained, and expanded science access beyond what their systems could formally provide. Section Two documents Finding 3.1 - Place-Based Science Leadership and Instruction, examining the micro level strategies through which leaders and educators translated place-conscious leadership philosophy into the daily reality of culturally resonant, identity-affirming science teaching and learning for the students who had been most consistently excluded from it.

**Finding 3.0 - Brokering Science Access for Marginalized Students**

Regardless of the significant barriers to science education for minoritized students in rural school systems, equity-focused leaders navigated their systems with awareness.

Against the backdrop of systemic and cultural/historical barriers documented in Chapter Four, rural science education leaders did not simply endure the conditions of inequity they described, they navigated them, innovating creative, relational, and structurally responsive strategies for brokering science access for the minoritized students their systems were failing. Finding 3.0 documents the macro and meso level navigational strategies that participants employed across all eleven participant accounts, strategies that operated at the organizational and community partnership level and that reflected the work of inclusive educational leadership across the dimensions of place, preparation, and practice in ways that the formal institutional structures of rural education had not provided.

***Macro Level Navigation***

At the macro level, the most significant navigational infrastructure documented in this study was the California NGSS Collaborative, described by Lemon Tree as an organizational architecture designed to do for rural science education what individual county offices and districts could not do alone: create a common message, develop science education leadership capacity, and produce professional learning that could travel to the most isolated corners of the state regardless of where students lived. The Collaborative represented a macro-level navigation strategy precisely because it operated at the level of organizational design, building the statewide infrastructure that individual rural systems lacked the personnel and resources to build for themselves. Lemon Tree described the essential function of this infrastructure with directness:

> This allows that common message to be shared across the state, regardless of where students live — which supports our county offices and our districts that are not just in urban settings that may not have the funding to do the work that needs to be done for science, but also in our rural settings that don't have the people to do the work. (Lemon Tree)

Magnolia described a parallel macro-level strategy through the county leadership networks developed in Kent and Ventura Counties, creating peer-to-peer professional learning spaces where teachers reported back on what worked and learned from each other across district boundaries that had previously isolated them. This was not simply professional development. It was the deliberate construction of professional community in contexts where professional isolation had been the structural norm, a macro-level navigation strategy that addressed the professional isolation documented in Finding 1.0 not by waiting for the system to provide community but by building it through the intentional design of learning spaces that crossed institutional boundaries. Torrey Pine described a macro-level strategy rooted in the National Science Foundation iTest program, a grant-funded professional learning infrastructure that recruited rural and tribal school communities in Arizona and San Diego County through university and science center partnerships, bringing professional learning to communities that had previously had none. The teachers who drove through snowstorms to attend described the experience in terms that revealed not gratitude for a generous gesture but hunger for the professional community that the structural conditions of rural education had systematically denied them:

> "Most of them have zero professional learning, like they don't have access to it — so they literally drove through snowstorms to get to it, to visit us. That was kind of wild, right? And they were like, so thankful. It was the most heart-filling experience for me in professional development work that I've ever done in my life." (Torrey Pine)

Ginkgo described a macro-level navigation strategy rooted in the redesign of the Glenn County STEM Expo, transforming what had been a small, exclusive, quality-first competition accessible primarily to students with the most resourced family backgrounds into a county-wide participatory science event that reflected the demographics of the community it served:

> I just want the kids to be excited about something and to see how it really connects to their local community. When you hold an event and the crowd that walks in the door is reflective of the demographics of the community, I feel like you've done something good. (Ginkgo)

Ginkgo's redesign of the STEM Expo was systematic and equity-oriented at every level, replacing performance-based prizes with skills-based badging that celebrated what every project demonstrated, randomizing donated prizes from the Exploratorium and Lawrence Hall of Science across all participating students rather than awarding them to the highest performers, translating the handbook into Spanish, and stacking the advisory board with people who were themselves underrepresented in science. One judge complained that these changes were making the science fair a race to the bottom, a response that Ginkgo described with restrained contempt and that named precisely the deficit thinking documented in Finding 2.0 that the redesign was designed to disrupt.

***Meso Level Navigation***

At the meso level, the most consistently documented navigational strategy across all eleven participants was the cultivation of deep, sustained community partnerships that extended the science education infrastructure of rural systems beyond what those systems could sustain internally. This finding, that local partnerships were referenced by 100% of participants, was the most universally documented navigational strategy in the study, and its universality was itself a finding: not a single rural science education leader in this study described equitable science access as something their system could produce alone. Every leader, without exception, had built or was building the community relationships through which science access became possible in their specific place.

Incense Cedar described a thirty-year practice of partnership development with the U.S. Forest Service, the California Department of Fish and Wildlife, Plumas Audubon Society, Feather River Trout Unlimited, Feather River Land Trust, Plumas Corporation, and Feather River College, a network of relationships that collectively constituted a parallel science education infrastructure, built not on fiscal resources but on shared mission and relational trust: "We can have the very best science education program in the whole state, not because we have the money, but because we have the relationships to do it."

This statement named a principle that operated across participant accounts at every tier of the study, the recognition that in rural science education, relationships were not a supplement to resources but a substitute for them, and that the work of building and sustaining those relationships was not peripheral to rural science education leadership but constitutive of it. Incense Cedar's partnership network had produced innovations that addressed the structural barriers documented in Chapter Four in ways that no policy change had managed to accomplish, the conservation of walkable learning landscapes adjacent to every school that eliminated the busing constraint, the pairing of every teacher with a local scientist that extended the professional learning infrastructure beyond what any single professional development event could accomplish, and the gear donation program that ensured no student was excluded from outdoor field science because they did not own a jacket or boots.

Pine described a meso-level brokering strategy rooted in the partnership between Mariposa Unified and the Sierra Foothill Conservancy and Mariposa Arts Council, the science arts camp that had become the centerpiece of the county's place-based science education program. But Pine also described a meso-level brokering strategy that illustrated the healthcare and workforce dimensions of science access, documenting the partnership with Columbia College through K-12 Workforce Funding to build out a healthcare pathway that provided students with licensed vocational nurse (LVN) certification upon graduation:

> There's one girl I'm thinking of specifically, right, that knew she needed to go straight into the workforce, was how she wrote, and the confidence that it built for her, you know, to see like, hey, like, I've got this, I can do it. And I think science is cool. And so learning how to do things in that medical field, and seeing yourself that way, and being in your scrubs, that is so amazing to watch. (Pine)

This story named something essential about what meso-level science access brokering required: not only the creation of science learning opportunities but the translation of those opportunities into futures that students could actually see themselves inhabiting. For this student, the LVN certification was not an abstract academic achievement but a concrete and visible pathway into a science-related career in a community where abstract academic achievement had never been sufficient evidence that science had anything to offer her.

Valley Oak described a meso-level navigation strategy that extended science access to the most marginalized students in the most unlikely settings, a juvenile hall where tanks of fish monitored by incarcerated students had become the entry point for two students who enrolled in community college biology courses while still incarcerated, motivated by the discovery that complex science content was within their reach without the academic prerequisites the standard science access narrative required:

> Even for a lot of them, just learning that they have the capacity to engage in really complex science concepts you don't need to necessarily have the highest level math or reading scores to be able to engage in some really high-level science content — broadening their idea of what is possible for them. (Valley Oak)

Oak documented a meso-level brokering strategy that was distinctively Siskiyou County, the contracted science instructor model, in which three county-employed science specialists were available for district contract to provide the hands-on, inquiry-based science instruction that rural classroom teachers could not themselves deliver. The school that contracted for 60 days of science instruction illustrated what was possible when the brokering strategy was fully resourced and sustained. Oak was in the process of transitioning this model toward instructional coaching, recognizing that the contractor model, while effective in delivering science instruction to students, did not build the teacher capacity that would ultimately be required for equitable science access to become sustainable:

> With our Cal MSCS funds, we've leaned into instructional coaching training for our science instructors. Each of our three instructors have picked a teacher that they know, a safe person, and they're going to work with them for six sessions to help them improve their science instruction. (Oak)

Douglas Fir developed the Science Leadership Exchange through CAL-MSCS funding, bringing together 27 teachers from every school site in Trinity County for monthly professional learning with stipend support, centering teachers' own questions and uncertainties about science instruction rather than delivering prescribed content: “We developed the Science Leadership Exchange, and we've got 27 teachers across the county participating. We have a teacher from every single site in the county.”

The watershed center partnerships that Douglas Fir had cultivated, guest science teaching, salmon harvest festivals, science camps, reforestation projects, represented a meso-level community partnership infrastructure that had become the practical backbone of science education in a county where the formal instructional system was unable to sustain it alone. Juniper described a set of meso-level navigation strategies in Humboldt County distinguished by their explicit equity orientation, the redesign of the science fair, the translation of materials, the revision of rubrics, the stacking of the advisory board, and the whole-district professional learning engagement that brought Zaretta Hammond to a county where every secretary and every bus driver was invited because the work of making science education equitable was understood as a whole-community commitment rather than a classroom-level practice. The Indian Education Council board at Klamath Trinity, a parallel governance structure that reviewed curriculum and policy alongside the school board with specific attention to the cultural responsiveness of educational decisions for Native American students, was described by Juniper as a powerful and sometimes politically complicated structural innovation that represented exactly the kind of community-accountable governance that equitable rural science education for Indigenous students required. Redwood described meso-level partnership strategies in Alpine County through the Washoe Cultural Department, the Alpine Watershed Group, and the tribal forestry department, partnerships that brought Indigenous environmental practices, water testing in the Carson River, and tree planting at Turtle Rock Park into the science education of a county where 43% to 59% of students were Native American and where the school's most powerful science learning experiences had been produced not by the formal curriculum but by the community relationships that had been built around it. Magnolia described the statewide professional learning networks of the California Science Project, peer-to-peer learning communities in Kent and Ventura Counties that were doing for rural science teachers what no single district-level professional development program could accomplish alone. And Lemon Tree described the story of a fifth-grade classroom in San Diego County where a teacher had done everything this study's navigational findings would have predicted, using student notebooks with fidelity, allowing students to use their home languages in science discourse, leaning into student talk, connecting science to real-world experience, and whose students, who were all English language learners, had outperformed every other class in the district on their end-of-year science assessment. This story illustrated that students themselves have capacity to learn science just as educators have capacity to instruct on science content. In addition to instructional practices that support all students, rural science spaces are also accessible for use in science education.

**Finding 3.1 - Place-Based Science Leadership and Instruction to Provide Science Instruction Support**

Place-based science instructional practices use the rural environment as an educational opportunity for student success. Place-based science leadership emerged as the most consistent, generative, and powerfully documented navigational strategy across this study. Where the systemic and cultural/historical barriers documented in Chapter Four described the conditions that made equitable rural science education structurally difficult, place-based science leadership described the conditions that made it possible, not by working around the constraints of rurality but by working through them, leveraging the natural, cultural, and community assets of specific rural places as the primary vehicle for science learning, identity development, and critical consciousness. This finding operates at the micro level of the macro-meso-micro navigational framework, documenting the instructional and relational practices through which rural science education leaders translated place-conscious leadership philosophy into the daily reality of science teaching and learning.

The principle that animated every account of place-based science leadership in this study was stated most directly by Lemon Tree:

> In rural districts, kids have real life, authentic experiences that can be leveraged for science. So if the teacher is willing to spend the time to get to know their kids and bring their real lives into the classroom, our students in rural settings have a lot of home life experiences that connect to what they're already learning, and can help students feel strong science identity, feel like they have a lot to bring to the table and share, and lead to those rich and robust discussions. (Lemon Tree)

This observation named the essential inversion that place-based science leadership required, the recognition that rural students were not deficit learners who needed science brought to them from outside but knowers whose prior knowledge of specific places, ecologies, and community practices constituted a scientific foundation that formal science instruction could build upon rather than replace. Valley Oak named the consequence of failing to make this inversion: a pervasive sense of apathy among rural students around career potential pathways, students not seeing options for themselves within their community that were there but not visible, a motivational gap that was not the product of student indifference but of a science curriculum that had never bothered to look at where students already were.

Incense Cedar provided the most fully elaborated account of place-based science leadership in the study, a thirty-year body of work that had produced a locally authored, district-adopted science curriculum built entirely from the places, ecology, history, and community relationships of Plumas County, without textbooks, without commercially produced resources, and without the assumption that the knowledge required for rigorous science education had to come from outside the community. The curriculum was organized around the disciplinary core ideas of the NGSS, change over time, patterns, systems, but it was enacted through the specific phenomena of the Sierra Nevada watershed: the macroinvertebrates of the Feather River, the salmon runs, the vascular systems of the sugar pines, the water cycle that connected a mountain kindergartner's backyard to the Pacific Ocean. Nature journaling and field sketch noting served as the primary assessment tools, portfolios that documented the evolution of student thinking across years, allowing each student to be measured not against a standardized benchmark but against their own developing understanding of the place they inhabited. Incense Cedar described the epistemological foundation of this approach with characteristic directness:

> One thing I learned from a professor of mine at Cal was, you either map yourself or someone else will map you. And if someone else maps you, they may label you, name you, put you in a legend and change your whole identity. And so we do a lot of map making because it's identity stuff, and every child can claim their own identity through the maps they make. (Incense Cedar)

The capstone of this curriculum, the sixth-grade Feather River watershed trip, in which students followed their river from its mountain headwaters all the way to the Pacific Ocean, camping along the way, encountering the farmers and wildlife refuge managers and water engineers whose lives were shaped by the same water that shaped theirs, was among the most powerful accounts of place-based science learning in this study:

> I've had kids in tears, and kids just in hysterics and joy, and never been to the ocean. And what that does for their frame of their own life, and how they belong to the bigger planet. And now they've experienced, they weren't just told they belong. They got to experience how they belong. (Incense Cedar)

This was the critical consciousness that Finding 2.0 had documented as consistently absent from rural science instruction, made visceral, made geographic, made irreversible. Students who had never left the county, whose socioeconomic circumstances had foreclosed the kind of travel and experiential breadth that their more privileged counterparts could assume, arrived at the Pacific Ocean with the understanding that their river, the water they drank and played in and fished from, was the same water that sustained 30 million Californians and almost a million acres of farmland. They had not been told they belonged to something larger. They had experienced it.

Incense Cedar also described the cultural and colonial dimensions of place-based science leadership, the restoration of Maidu place names in the curriculum, the critique of colonial naming practices through the lens of species and geographic names, the map-making that gave every student the tools to claim their own identity rather than accepting the identity that others had assigned to their places. This was not supplemental to the science. It was the science, an inquiry into the historical and political conditions under which knowledge of the natural world had been produced, distributed, and assigned authority, conducted through the disciplinary practices of geography, ecology, and systems thinking.

Pine described a parallel place-based navigational strategy in Mariposa County, the science arts camp run in partnership with the Mariposa Arts Council and the Sierra Foothill Conservancy, in which students visited the same three places, the Stookey Preserve, the Creek Parkway, and Yosemite, repeatedly across a six-week period, building the ecological depth that single-visit field trips could never produce. The design principle was powerful in its simplicity: instead of taking students somewhere once and moving on, the program brought students back to the same places again and again, allowing them to watch things change over time, track phenomena across visits, and develop the kind of sustained observational relationship with a place that scientific understanding required. The moment Pine described was among the most memorable accounts in this study:

> One kiddo in particular that I'm thinking of just absolutely lighting up when we got permission to take our students into certain parts of Yosemite and the kid being like, my grandma took me here, right? Like I know about this place. (Pine)

The child's prior knowledge was not incidental to the science instruction, it was the science instruction. The child who recognized her grandmother's place in Yosemite was not a passive recipient of place-based learning. She was an active knower whose relationship to that place was a foundation to build upon, a scientific resource that the curriculum honored rather than erased. Pine also described the development of Teacher Camp, a professional learning initiative in which teachers would go to the same places as the students, without the students, as a cohort, engaging in the same lessons and materials in order to develop the same linguistic and conceptual foundation that the Conservancy was building with students. This was place-based professional learning, the recognition that teachers could not bring the places of their community into their science instruction without first developing their own relationship to those places.

Douglas Fir described the place-based science leadership of Trinity County through the lens of the Watershed Center, a community organization that had become the de facto science education infrastructure for a county whose school system could not sustain it alone. The Watershed Center's guest science teaching model, its salmon harvest festivals, its reforestation projects in the aftermath of the Tamarack fires, and its Career Ready Labs grounded in the Paxton Patterson kits represented a sustained institutional expression of the same place-based principle, that the ecology, the history, and the environmental challenges of Trinity County were not merely contexts for science learning but its content. Douglas Fir described the aspiration that animated the Science Leadership Exchange with equal clarity:

> I think those stories often humanize it a lot more. And I think that often ends up wrapping in those marginalized or minoritized students, where they can see that windows and mirrors concept and can see themselves or people they know in the science that they're doing, just more of that, just more of it. (Douglas Fir)

Redwood described place-based science leadership in Alpine County through the lens of the partnerships that had produced the most powerful science learning experiences in the study's most remote county, the water testing in the Carson River conducted with the Alpine Watershed Group every fall and spring, the reforestation project at Turtle Rock Park conducted with the tribal forestry department and the U.S. Forest Service on a site sacred to the Washoe Tribe, and the Expanded Learning Opportunities Program (ELO-P) at the West County school in which students worked through John Muir's hiking guide and conducted their own hikes in the Stanislaus National Forest. The Turtle Rock Park story was among the most evocative accounts of place-based science learning in the study:

> Those kids when they got back on the bus, there were middle school kids who I had seen do nothing but swear at people and have just like the, you know, they have to be the cool kid kind of attitude just like, smiling and acting like children. All of

> these kids came back with dirty fingers and big smiles getting on a school bus. (Redwood)

Redwood named what had produced this transformation with characteristic simplicity: the kids needed to see how science connected to their local community. The Washoe Tribe's involvement in the reforestation project, with tribal cultural department staff present, with tribal forestry workers whose children attended the school working alongside students, with the intergenerational and whole-community character of the event that had brought county supervisors to the meeting to brag about what the kids had accomplished, was not an enrichment add-on. It was the science, enacted in the place where science and culture and community and identity met in ways that no textbook could have produced and no standardized assessment could have measured.

Oak documented the most recent and in some ways the most poignant expression of place-based science leadership in this study, the Junction Elementary river ecology unit, created by a second-year intern teacher at the end of a two-hour drive down the Klamath River, for 22 students in grades TK through third grade, built entirely around the ecosystem of the river that ran past their school:

> They looked at the ecosystems, they looked at macro invertebrates, so many things that were just focused on, where do you live? We are right here in this beautiful place. Let's learn more about it. And the kids were so engaged, it was a very successful unit. (Oak)

The teacher left the profession at the end of the year. This detail, added by Oak with a brevity that named its own devastation, brought Finding 3.1 into direct and necessary contact with the structural story of Chapter Four. Place-based science leadership worked. The evidence across all eleven participants was abundant, vivid, and consistent. It worked for the Native American student who recognized her grandmother's place in Yosemite. It worked for the sixth grader who cried at the Pacific Ocean. It worked for the students whose dirty fingers and big smiles got on the school bus at Turtle Rock Park. It worked for the incarcerated student who discovered that he could engage with complex science content without a math prerequisite and went on to enroll in college biology. It worked for the 22 students on the Klamath River who learned where they lived through the macro invertebrates in the water at their feet. But it required teachers who had the capacity, the support, the cultural grounding, and the professional stability to sustain it. In a system defined by the structural conditions documented in Chapter Four, those conditions were not reliably present. The navigation documented in this chapter was real, and it was powerful, and it was insufficient not because of the leaders who enacted it but because of the systems within which they were compelled to enact it.

Valley Oak captured this tension between possibility and structural constraint in the observation that became the study's most precise statement of what place-based science leadership could accomplish and what it could not:

> Keeping your examples hyper local, kids need to see it's happening in their own backyard, not in Washington, not in the Amazon, right, not in these obscure places. It is happening here, and here's what we can do to support our local community. (Valley Oak)

Here was the science curriculum that rural minoritized students deserved, rooted in the places they knew, connected to the communities they belonged to, building on the ecological and cultural knowledge they already carried, and pointing toward futures they could actually inhabit. The leaders in this study had been building it, in a hundred different forms, with whatever relationships and resources and relational trust they had been able to accumulate. Their navigation was a testament to what was possible. The structural conditions of their systems were a testament to what remained necessary. Chapter Six presents the conclusions, analysis, and recommendations that the evidence of both chapters demands.

**Summary**

This chapter presented the findings of this study in response to Research Question Two: *How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?* Two findings were documented across two sections, addressing the navigational strategies that rural science education leaders developed in response to the systemic and cultural/historical barriers documented in Chapter Four.

Section One documented Finding 3.0 - Brokering Science Access for Marginalized Students, examining the macro and meso level strategies through which rural science education leaders created, sustained, and expanded science access beyond what their systems could formally provide. At the macro level the California NGSS Collaborative, the NSF-funded professional learning networks of Torrey Pine, the county leadership networks of Magnolia, and the STEM Expo redesign of Ginkgo emerged as organizational infrastructures designed to do collectively what individual rural systems could not do alone. At the meso level the findings documented a rich and varied set of community partnership strategies across all eleven participants, from the thirty-year NGO network of Incense Cedar to the contracted science instructor model of Oak, from the healthcare pathway partnership of Pine to the juvenile hall fish tanks of Valley Oak, from the Science Leadership Exchange of Douglas Fir to the Watershed Center partnerships of Douglas Fir, from the equity-oriented science fair redesign and whole-district professional learning investments of Juniper to the tribal and watershed partnerships of Redwood, from the statewide infrastructure of Lemon Tree to the university and science center networks of Torrey Pine. The universality of local partnerships, referenced by 100% of participants, was itself the most significant finding of Section One: not a single rural science education leader in this study described equitable science access as something their system could produce alone.

Section Two documented Finding 3.1 - Place-Based Science Leadership and Instruction, examining the micro level strategies through which rural science education leaders and educators translated place-conscious leadership philosophy into the daily reality of science teaching and learning for minoritized students. The findings documented a consistent and theoretically grounded pattern across all eleven participant accounts: the most powerful science learning experiences described in this study were those that began where students already were, in the specific places, ecologies, histories, and community relationships of their rural homes and built outward from there toward the disciplinary knowledge, scientific practices, and critical consciousness that rigorous science education demanded. From Incense Cedar's Feather River watershed curriculum to Pine's science arts camp, from Redwood's Turtle Rock Park reforestation to Oak's Klamath River ecology unit, from Juniper's student who rendered the science of DNA not in a laboratory report but in a hand-drawn comic strip that told the story of inheritance through the faces and names of his own community, to Valley Oak's juvenile hall fish tanks. Accounts of successful science learning for minoritized rural students in this study were an account of science that began where students already were, in their places, their languages, their relationships, and their ways of making meaning, and built outward from there toward the disciplinary knowledge and scientific practices that rigorous science education demanded rather than delivering understanding and hoping students would find a place for it.

The findings of this chapter, taken together, revealed a body of navigational wisdom that was both practically urgent and theoretically significant, urgent because the students whose science education depended on it could not wait for the structural transformation that remained necessary, and significant because it illuminated what equity-oriented rural science education leadership looked like when it was enacted with creativity, cultural grounding, relational depth, and genuine love for the places and the students it was designed to serve. These navigational strategies did not resolve the structural contradictions documented in Chapter Four. But they named what was possible within them and they pointed, with considerable force, toward what structural transformation would need to make permanently possible for all rural minoritized students, in all rural communities, without requiring extraordinary individual leadership to sustain it. Chapter Six presents the conclusions, discussion, and recommendations that both chapters together demand.

# Chapter Six: Conclusions, Discussion, and Recommendations

## Introduction

This concluding chapter brings together the findings of this study to offer conclusions about what the evidence may mean, a discussion that situates those conclusions within the existing body of scholarly literature and the theoretical frameworks that guided this inquiry, and present recommendations directed toward the structural transformation that the evidence suggests may be necessary.

The study documented what appear to be the systemic and cultural/historical barriers that rural science education leaders in California encountered in supporting the science education of minoritized and marginalized students, and the navigational strategies those leaders developed in response. The analysis woven throughout this chapter suggests that those barriers may not have been primarily the product of individual failure or local neglect but of institutional design, racialized organizational structures, inadequate accountability mechanisms, chronic underfunding, deficit thinking, and the weight of colonial and political history, and that the navigational strategies of even the most creative and committed rural science education leaders may have been insufficient alone to produce the structural transformation that equitable rural science education appears to require.

This chapter draws on the full body of evidence produced by this study, including data from the pilot study that preceded the larger investigation, to offer conclusions about what the findings may mean, what they appear to demand, and what might need to change if rural science education is to fulfill its democratic promise for the students who have been most systematically denied it. The recommendations that follow are organized across three domains: research, policy, and practice, and are examined through the macro, meso, and micro analytical lens that has organized this study's findings throughout. Together these recommendations constitute not a checklist of incremental improvements but a call for the coordinated, structural, and sustained response that the evidence of this study appears to make necessary.

## Conclusions

The findings of this study, taken together with the evidence produced by the pilot study that preceded it, appear to support a set of conclusions that are both analytically grounded and practically urgent. These conclusions are offered not as definitive truths but as interpretations that emerged from the convergence of eleven participant accounts, three theoretical frameworks, and the researcher's own place-conscious and postmodern interpretive lens — and that are consistent with the broader body of literature on rural education equity, science education reform, and culturally relevant pedagogy.

The pilot study involved interviews with three rural science education leaders and was designed to test and refine the research instruments and design for the larger study. The larger study extended the sample to eleven participants across three tiers of rural California science education leadership for a combined total of fourteen rural science education leaders whose experiences and perspectives informed the full body of evidence on which these conclusions are based. Among the participants was a retiring rural science education leader with over thirty years of experience in the same rural county, a participant whose three decades of sustained leadership in a single place appeared to provide a longitudinal perspective on the conditions of rural science education that no other participant could have offered, and the incoming science leader who assumed that position, whose early career perspective appeared to illuminate both the promise and the challenges of building the next generation of rural science education leadership capacity. Together these two participants offered what may be a rare and analytically significant window into the continuity and change of rural science education leadership across time, and their paired accounts appeared to deepen the study's interpretive conclusions about the structural persistence of the barriers documented throughout this dissertation.

The first conclusion is that the barriers to equitable science education for minoritized students in rural California appear to be structural, persistent, and compounding. The data suggest these barriers have resisted decades of standards reform, curriculum adoption, and equity advocacy. They may be embedded in the institutional architecture of rural educational systems, in the accountability structures that exempt science from consequence, the funding mechanisms that withhold professional learning resources from science educators, the policy designs that assume urban conditions and produce rural misalignment, and the historical practices of exclusion and assimilation that have shaped the relationship between rural schools and the Indigenous and minoritized communities they serve. The evidence is consistent with the interpretation that these barriers will not be resolved by incremental policy adjustments or individual leadership excellence alone. They appear to require structural transformation.

The second conclusion is that rural science education leaders appeared to navigate with extraordinary creativity, relational depth, and cultural grounding against structural conditions that may make equitable outcomes structurally difficult to sustain. The navigational strategies documented in this study, place-based curriculum innovation, community partnership networks, contracted science instructors, equity-oriented professional learning redesign, and the cultivation of succession in rural science education leadership appeared to be real, powerful, and worthy of replication and investment. They also appeared insufficient to close the structural gaps that produced the inequities they were designed to address. The data suggest that navigation may not be transformation and that the students whose science education depends on extraordinary individual leadership deserve structural conditions that make equity possible without requiring that leadership to be extraordinary.

The third conclusion is that indigenous students appear to be among the most severely and consistently marginalized populations in rural science education and that this reality may have been insufficiently acknowledged, theorized, and addressed in the existing research and policy landscape. The boarding school trauma, the intergenerational distrust of educational institutions, the artificially deflated standardized test scores, the tracking systems that appeared rooted in racial identity rather than academic capacity, and the erasure of indigenous epistemological traditions from the science curriculum, these appeared not as peripheral findings of this study but as central ones, documented across multiple participant accounts and pointing toward the need for a sustained and accountable policy and practice response.

The fourth conclusion is that the distinctive markers of rural educational leadership, closeness to community, high visibility and vulnerability, and the many hats phenomenon, appear to be structural conditions that may simultaneously enable and burden the work of equity-oriented rural science education leadership. They may be the conditions that make the most powerful navigational strategies possible and the conditions that make equity-oriented leadership personally and professionally costly in ways that the existing literature has not fully reckoned with. Any structural response to the barriers documented in this study may need to attend to these markers not as individual leadership challenges to be managed but as systemic conditions to be understood, supported, and where possible relieved.

## Discussion

The conclusions offered above do not emerge from this study in isolation. They enter a scholarly conversation that has been building for decades across the literature on rural educational leadership, science education reform, and culturally relevant pedagogy, a conversation that the findings of this study appear to confirm, extend, and in some cases complicate. This discussion situates the conclusions of this study within that broader conversation, bringing participant accounts into dialogue with the three theoretical frameworks that guided this inquiry and with the scholarly literature that framed it.

### *Connecting the Theoretical Frameworks: An Integrated Analytical Architecture*

The three theoretical frameworks applied in this study, Ray's (2019) Theory of Racialized Organizations at the macro level, Young and Arnold's (2020) Emerging Framework for Inclusive Educational Leadership at the meso level, and Ladson-Billings' (1995) Culturally Relevant Pedagogy at the micro level, were not designed to produce three parallel analyses but to illuminate three dimensions of what may be a single, interconnected phenomenon: the structural reproduction of inequity in rural science education across the organizational, leadership, and instructional levels simultaneously.

The connection between Ray's (2019) framework and Young and Arnold's (2020) framework is visible in the way that the racialized organizational conditions documented at the macro level appeared to shape the leadership conditions documented at the meso level. The dashboard accountability gap, the exemption of science from differentiated assistance determinations as what may be a racialized organizational design choice, appeared to produce exactly the leadership preparation and practice conditions that Young and Arnold's framework identifies as most consequential for inclusive educational leadership: leaders who could not prioritize science professional learning because the accountability architecture did not require it, leaders whose place-specific knowledge of their communities was insufficient protection against the political dynamics that the same racialized organizational logics had produced, and leaders whose many hats left them without the time or cognitive bandwidth to develop the specialized science education leadership expertise that NGSS demanded. The racialized organizational conditions that Ray (2019) described at the macro level appeared, in other words, to cascade downward through the leadership conditions that Young and Arnold (2020) analyzed at the meso level, producing a compressed, under-resourced, and politically exposed rural science education leadership landscape whose structural conditions made inclusive practice difficult to sustain even when individual leaders were deeply committed to it.

The connection between Young and Arnold's (2020) framework and Ladson-Billings' (1995) framework is visible in the way that the leadership preparation and practice gaps documented at the meso level appeared to produce the cultural competence and critical consciousness gaps documented at the micro level. Leaders who had not been adequately prepared to support culturally responsive science instruction, whose preparation programs had not attended to the specific epistemological traditions of the Indigenous and multilingual communities they served, whose professional learning systems had not cultivated the place-conscious awareness that culturally sustaining science pedagogy required, could not reliably produce the instructional conditions that Ladson-Billings' framework identified as essential for the science learning of minoritized students. The leadership preparation gap that Young and

Arnold (2020) pointed toward appeared, in other words, to cascade downward through the instructional conditions that Ladson-Billings (1995) analyzed at the micro level, producing classrooms where Alina's multimodal scientific thinking went unrecognized, where English learner students went entire school days without a speaking or listening opportunity in science, and where the ecological and cultural knowledge that rural minoritized students carried to school went systematically unhonored.

The connection between Ray's (2019) framework and Ladson-Billings' (1995) framework is perhaps the most analytically significant of the three, connecting the structural findings of Chapter Four with the cultural findings of the same chapter. The racialized organizational conditions that Ray described at the macro level, the historical design of schools for white children or for Native children to be assimilated, as Juniper articulated it, appeared to produce exactly the cultural responsiveness gap that Ladson-Billings' framework identified at the micro level: classrooms where the knowledge, languages, and ways of knowing that Indigenous and other minoritized students brought to science learning were systematically devalued, not because individual teachers chose to devalue them, but because the organizational norms, assessment frameworks, and curriculum designs within which those teachers worked had been constructed on epistemological foundations that did not recognize them as knowledge at all. National Academies of Sciences, Engineering, and Medicine (NASEM,2022) argued that science education is not a neutral field but one in which European ways of knowing have been systematically elevated at the expense of other epistemological traditions, and this argument is consistent with the integrated interpretation that emerges when Ray's macro-level analysis and Ladson-Billings' micro-level analysis are read together: that the cultural responsiveness gap in rural science education may not be primarily a pedagogical problem to be solved through teacher professional development alone, but an organizational problem to be addressed through the transformation of the institutional structures and epistemological assumptions that produce and reproduce it.

The navigational strategies documented in Chapter Five are illuminated by this integrated analytical architecture in a particularly significant way. The place-based science education documented across all eleven participants appears, through this integrated lens, as the navigational strategy most directly responsive to all three dimensions of the inequity the frameworks described, operating simultaneously at the organizational level by building community partnership infrastructures that supplement the racialized resource distribution documented by Ray, at the leadership level by cultivating the place-conscious, relational, and community-embedded practice that Young and Arnold described as the foundation of inclusive educational leadership, and at the instructional level by creating the conditions of student learning, cultural competence, and critical consciousness that Ladson-Billings identified as the essential components of equitable science teaching. The convergence of all three analytical frameworks on place-based science education as the most powerful and most consistently documented navigational strategy in this study may not be coincidental; it may be that place-based science education is the approach most naturally suited to simultaneously addressing the organizational, leadership, and instructional dimensions of the inequity that this study documented.

### ***The Research Desert Cycle and the Structural Persistence of Rural Science Education Inequity***

The conclusion that the barriers to equitable rural science education appear structural, persistent, and compounding is consistent with what Thier et al. (2021) identified as the research desert cycle, the self-reinforcing dynamic in which the absence of research on rural education leads to the absence of targeted policy and funding, which in turn perpetuates the conditions that make rural communities difficult to study and serve. Showalter et al. (2023) documented the chronic underfunding and structural disparities that have long characterized rural education, and the accounts of Oak, Redwood, Pine, and Incense Cedar across this study appear consistent with their findings, suggesting that the structural conditions of rural science education may have changed remarkably little despite the multiple waves of standards reform and equity advocacy that have swept through California education in recent decades. Grant et al. (2024) argued that clearer, multi-dimensional definitions of rurality are essential to producing credible, transferable research and addressing research deserts and the three-tier participant selection methodology of this study, which used the California Rural Counties Task Force framework rather than the urban-centric NCES locale codes, represents one methodological response to that call.

### *The Many Hats Phenomenon and the Limits of Rural Leadership Capacity*

The conclusion that the many hats phenomenon appeared to compound the capacity deficit of rural science education leaders is consistent with what Copeland (2013) documented in his examination of rural superintendent leadership — the structural reality that rural leaders occupy multiple roles simultaneously in ways that may leave insufficient time and cognitive bandwidth for the sustained, specialized instructional leadership that science education reform requires. McHenry-Sorber and Sutherland (2020) extended this analysis by documenting the tensions rural leaders face in honoring local culture while simultaneously striving for district-wide equity, a tension that appeared throughout the findings of this study in the accounts of leaders who navigated conservative community politics while trying to advance equity-oriented science instruction. Zuckerman et al. (2018) identified limited absorptive capacity as a defining constraint of rural educational systems, and the accounts of Redwood, Oak, Ginkgo, and Magnolia are consistent with this finding, suggesting that the many hats phenomenon may function as a structural constraint on absorptive capacity, producing a rural science education leadership landscape in which even well-designed professional learning investments appear unable to gain the institutional traction required to produce sustainable change.

### *The De-Prioritization of Science and the Accountability Gap*

The conclusion that science education appeared to be systematically deprioritized in rural educational settings through the absence of meaningful accountability structures is consistent with what NASEM (2022) identified as the need for a systems-aware approach to science education that attends to teachers, professional learning, and curricula as interconnected components of a coherent whole. The dashboard accountability gap documented across seven of eleven participants is consistent with what Anderson et al. (2018) documented about the relationship between accountability structures and NGSS implementation in under-resourced systems, suggesting that producing measurable gains in student science capacity may require the kind of sustained professional development investment that rural systems appear structurally unable to prioritize in the absence of institutional pressure. Magnolia's finding that professional learning block grant funds appeared to sit unspent because the policy design had not included science as an eligible use is consistent with what Thier et al. (2021) described as the policy invisibility of rural science education needs, and points toward a structural gap between the rhetoric of NGSS implementation as a statewide priority and the fiscal and accountability architecture that might make that implementation possible in rural contexts.

The convergent and unsolicited emergence of CAL-MSCS across three independent participant accounts is consistent with this interpretation and warrants specific analytical attention. Three of eleven participants, representing 27% of the study's rural science education leaders, identified Cal MSCS as the primary financial infrastructure supporting their science education capacity building work, doing so without prompting from the interview protocol. It is worth noting that the researcher serves as a member of the California Science Steering Team and therefore has professional familiarity with the Cal MSCS initiative and its funding landscape. Cal MSCS was not a subject of the interview protocol, and no questions about it were asked of participants. Its emergence as a primary funding infrastructure across three independent accounts was an unsolicited and convergent finding, one whose significance the researcher was positioned to recognize precisely because of the statewide science leadership context in which this study was conducted. This finding is consistent with what Thier et al. (2021) described as the policy invisibility of rural science education needs, suggesting that in the absence of dedicated state investment in rural science professional learning, rural science education leaders may have been turning to the only available funding stream capable of supporting the work, regardless of whether that stream was designed or resourced to carry the full weight of rural science professional learning infrastructure. The analytical significance of this finding may lie not in the fact that Cal MSCS was being used for science; it was designed to support science alongside mathematics and computer science, but in the possibility that its absence would expose a gap that no comparable initiative currently exists to fill.

### *Deficit Thinking and the Cultural Competence Gap*

The conclusion that limited cultural competence appeared as a significant barrier to equitable rural science education is consistent with what Ladson-Billings (1995) identified as the failure to affirm students' cultural backgrounds as foundational to both academic success and critical consciousness. The deficit thinking documented across participant accounts is consistent with what Lewis-Durham and Saastamoinen (2022) described as the pervasive creep of deficit perspectives in school leadership, and with what Kirchgasler and Yolcu (2022) documented as the production of hierarchies of science and mathematics access through apparently humanitarian educational practices. The finding that multilingual learners appeared to go entire school days without a single speaking or listening opportunity in science classrooms is consistent with what Moore (2007) identified as the gatekeeping function of science language and with what Lee et al. (2021) described as the need for human-centered approaches to science education that begin with students' lived experiences. Hammond (2015) connected cultural affirmation to brain development, demonstrating that the kind of culturally responsive science teaching that participants described in their navigational accounts may produce not only motivational benefits but deeper cognitive engagement and the accounts of student transformation documented by Pine, Redwood, Juniper, and Incense Cedar are consistent with Hammond's findings, suggesting that place-based, culturally affirming science instruction may produce exactly the cognitive and identity outcomes that the NGSS envisions.

### *The Historical Dimensions of Indigenous Student Marginalization*

The conclusion that Indigenous students appeared to be among the most severely and consistently marginalized populations in rural science education is consistent with what Joubert and Lensmire (2021) argued about the urgency of racial justice in rural communities and with what Grant-Panting (2021) documented about the need for equity organizing that takes the specific conditions of rural communities seriously. Ray's (2019) framework appears particularly relevant to the Indigenous findings, the suggestion that organizations are racialized by design is consistent with Juniper's historical account of the boarding school system, Redwood's documentation of the Stewart Indian School closing in 1980, and the artificially deflated CAST scores that Juniper described as the product of Indigenous families' intergenerational distrust of assessment systems. NASEM (2022) argued that science education was not a neutral field but one in which European ways of knowing have been systematically elevated at the expense of other epistemological traditions and the accounts of Incense Cedar's restoration of Maidu place names, Redwood's integration of Washoe cultural practices, and Juniper's partnership with the Indian Education Council board are consistent with NASEM's call for a more epistemologically inclusive approach to science education that honors Indigenous ways of knowing as legitimate scientific knowledge rather than cultural artifacts to be acknowledged and set aside.

### *Place-Based Science Education as a Vehicle for Equity*

The conclusion that place-based science leadership appeared as the most consistent and generative navigational strategy across the study is consistent with what Azano and Biddle (2019) described as the need for problem formation in rural education that is rooted in local context and equity rather than imported from urban frameworks. The accounts of Incense Cedar's Feather River curriculum, Pine's science arts camp, Redwood's Turtle Rock Park reforestation, and Oak's Klamath River ecology unit are consistent with what Aikenhead (2001) documented as the power of cross-cultural science teaching that integrates students' ways of knowing with Western scientific frameworks and with what Paris and Alim (2014) described as the essential commitment of culturally sustaining pedagogy to preserving and revitalizing the cultural and linguistic practices of historically marginalized communities. Ricket, Yahn, and Bentley (2023) demonstrated that rural educational leaders who acted as connectors between schools, students, and the local economy created career-connected learning experiences that fostered belonging and civic engagement and the findings of this study are consistent with their analysis. The universal documentation of local partnerships across all eleven participants is consistent with Harmon (2017) and Wargo et al. (2021), who identified relational trust and community collaboration as the foundational practices of effective rural educational leadership and points toward the possibility that community partnership may not be supplemental to equitable rural science education but constitutive of it.

## Synthesis: The Continuing Struggle and What It May Reveal

The three analytical lenses applied in this chapter and the integrated analytical architecture through which they are connected, together suggest a set of cross-cutting interpretive possibilities that the findings of this study appear to support. These interpretations are offered not as definitive conclusions but as analytically grounded propositions that emerge from the convergence of participant accounts, theoretical frameworks, and the researcher's own place-conscious interpretive lens.

The barriers documented in this study may not be new. They appear not to be the product of the pandemic, or the NGSS transition, or the current political moment, though each of these may have intensified them. The NGSS may not have created the teacher capacity deficit; it may have revealed it. The dashboard may not have created the de-prioritization of science, it may have institutionalized it. The political polarization of rural communities may not have created the tension between science education and conservative cultural values, it may have intensified a tension that had always been present. The retiring leader with over thirty years of experience appeared to provide longitudinal evidence for the continuing nature of these structural barriers, suggesting that the challenges documented in 2025 and 2026 may have been recognizably similar to those that had defined rural science education leadership throughout their career. The incoming science leader who succeeded this retiring participant represented both the hope and the risk of rural science education leadership succession: the hope that the relational capital, the community knowledge, and the curricular innovation built over decades could be transmitted and sustained, and the risk that without deliberate succession planning, structural support, and institutional memory, the work would need to be rebuilt from the beginning with every leadership transition. This longitudinal pattern is consistent with an interpretation that treats the continuing nature of this struggle as itself an analytically significant finding, one that points toward the possible inadequacy of incremental policy responses and the potential necessity of structural transformation.

The closeness between rural leaders and their communities, the high visibility and vulnerability that appeared to result from that closeness, and the many hats phenomenon that appeared to compress multiple leadership roles into single individuals may not have been merely challenges to be managed. They are consistent with an interpretation that treats them as structural features of rural educational leadership that simultaneously enabled the most powerful navigational strategies documented in this study and made equity-oriented leadership personally and professionally costly in ways that the existing literature may not have fully reckoned with.

The political polarization of rural communities is consistent with an interpretation that treats this not as a temporary disruption of an otherwise functional system but as a structural feature of the rural educational landscape that may require sustained analytical and practical attention. Grant-Panting (2021) and Joubert and Lensmire (2021) argued that rural was not raceless and not apolitical and the findings of this study appear consistent with both claims, suggesting a rural educational landscape in which the political may have always already been present in the work of science education leadership, and in which the leaders who navigated it most effectively appeared to be those who had developed the place-conscious political awareness to work within and sometimes around it without compromising their equity commitments.

Perhaps the most analytically significant pattern across the findings and one that may most powerfully challenge the dominant imagination of rural education equity is the apparent centrality and severity of Indigenous student marginalization in rural California science education. The convergence of accounts across participants is consistent with an interpretation that treats Indigenous student marginalization not as a variant of general rural poverty but as a specific, historically rooted, institutionally reproduced condition that demands its own analytical framework, its own policy response, and its own practice innovations. This interpretation is not offered with certainty; it is offered as a grounded analytical possibility that the data appear to support and that the rural education literature may not yet have fully addressed.

The navigational strategies documented in Chapter Five appear creative, committed, and relationally deep, and the data suggest they may have been insufficient alone to produce the systemic change that equitable rural science education may require. This is not an interpretation that diminishes the leaders who enacted these strategies. It is an interpretation that honors them by naming clearly that what they accomplished was remarkable given the structural conditions within which they worked, and that what the structural conditions produced was a system in which equity required heroism rather than producing it as a default outcome. Navigation within a racialized organizational system may not be the same as transformation of that system. The recommendations that follow are directed toward that transformation.

## Recommendations

The recommendations that follow are grounded in the findings, analysis, and discussion of this study and are organized across three domains: research, policy, and practice, examined through the macro, meso, and micro analytical lens that has organized this study throughout. They are offered not as a comprehensive reform agenda but as a set of priority directions, the places where the evidence of this study most urgently points and where investment, attention, and structural change may have the greatest impact on the rural science education leaders and the minoritized students whose futures this study has sought to illuminate.

### *Recommendations for Research*

**Macro Level — Building the Knowledge Infrastructure for Rural Science Education Equity.** The first and foundational recommendation of this study is an investment in research on rural educational leadership in science education, research designed, conducted, and disseminated with the specific conditions, contexts, and communities of rural California and rural America in mind. The research desert cycle that Thier et al. (2021) documented cannot be broken without a deliberate and sustained commitment to producing the knowledge base that rural science education policy and practice require. What appears to be needed is a sustained program of research that examines rural science education leadership across regions, demographics, and governance structures; that attends specifically to the experiences of Indigenous and other minoritized student populations in rural contexts; that follows leaders and students across time to document the longitudinal effects of structural conditions and navigational strategies; and that centers the voices, knowledge, and wisdom of rural communities themselves as the primary source of insight about what their schools and students need. Research on rural educational leadership should also attend to the succession challenge documented in this study, the question of how the knowledge, relationships, and curricular innovations built by experienced rural science education leaders may be transmitted, sustained, and built upon rather than lost with every leadership transition. Longitudinal research that follows leadership succession in rural science education contexts could produce evidence of significant practical value for the systems and communities working to sustain equitable science education leadership across time.

**Meso Level — Building Local Research Capacity.** At the meso level, this study points toward the value of practitioner research and local data systems in rural science education contexts research conducted by and with rural science education leaders themselves rather than about them from the outside. The shadowing methodology that Ginkgo described in Glenn

County going into classrooms to document the daily experience of English learner students in science is consistent with what Anderson and Herr (1999) described as researcher-practitioner validity, and represents exactly the kind of local, contextually grounded data collection that may produce actionable knowledge for rural science education leaders. Supporting rural science education leaders to conduct, interpret, and act on local research through professional learning networks, county office research capacity, and university-practice partnerships may produce a more direct return on investment in rural science education equity than research conducted at a remove from the communities it seeks to serve.

**Micro Level — Centering Student Voice in Rural Science Education Research.** At the micro level, the findings of this study are consistent with what Juniper described as the essential research practice, talking to students and listening to what they say about their science learning experiences. The student science belief surveys, the empathy interviews with families of English learners, and the multilingual learner shadowing documented across participant accounts all pointed toward student voice as an underutilized and potentially powerful data source for rural science education improvement. Research that centers the experiences, perspectives, and aspirations of rural minoritized students, conducted with the cultural competence and community trust that the findings of this study suggest are prerequisite, may produce evidence of particular relevance for the policy and practice recommendations that follow.

### *Recommendations for Policy*

**Macro Level — Redesigning Policy for Rural Contexts.** The second recommendation is that policy at the state and federal levels be created and reformed on the basis of the specific needs of rural science education leaders to access and serve their contextualized locations, not adapted from urban policy frameworks but designed from the ground up with rural conditions, constraints, and communities in mind. Crain (2023) argued that institutional notions of rurality are socially constructed in ways that reinforce inequality, and the policy landscape documented in this study, dashboard accountability structures that exempt science, professional learning funding that excludes science, compensation models that fund only two high school science courses, and program rollout designs that inadvertently eliminated services for the highest-need rural students, appears consistent with that argument.

Specifically, the evidence of this study appears to support the following policy directions. The California school dashboard should be reformed to include science as a metric subject to differentiated assistance determinations, removing the structural exemption that has allowed science de-prioritization to persist without institutional consequence. The professional learning block grants currently restricted from science use should be reformed to explicitly permit and incentivize their use for science professional learning, with targeted allocations for rural districts that lack the fiscal capacity to supplement state funding with local resources. The state's compensation model for high school science should be expanded to fund a minimum of three science courses rather than two, ensuring that students are not assessed on content the system has not provided them the opportunity to learn. Rural-specific science education leadership positions, analogous to the learning specialist model documented by Juniper in Humboldt County, should be funded at the county office level across California's rural counties, creating the infrastructure of specialized science education leadership that rural systems currently appear to lack.

This study also calls for the refunding and expansion of CAL-MSCS with explicit attention to the specific professional learning needs of rural science education leaders. Three of eleven participants, representing 27% of the study's rural science education leaders, identified CAL-MSCS as the primary financial infrastructure supporting their science education capacity building work. The fact that 27% of participants in a study specifically designed to reach the most rural and under-resourced science education leaders in California were dependent on a single initiative to fund the professional learning infrastructure their systems required speaks to the depth and urgency of the gap that CAL-MSCS was being asked to fill. This study calls for CAL-MSCS to be explicitly refunded with rural science education leadership development named as a priority use within its funding structure, and for the investment levels to be made commensurate with the scale of need that the evidence of this study has documented.

Policy reform in rural science education must also attend to the specific conditions of Indigenous communities, ensuring that the culturally responsive, community-accountable governance structures documented in this study, such as the Indian Education Council board at Klamath Trinity described by Juniper, are recognized, resourced, and supported as legitimate and necessary dimensions of rural science education governance rather than as exceptional accommodations.

**Meso Level — Policy Flexibility for Rural Contexts.** At the meso level, the findings of this study appear consistent with a call for policy flexibility that recognizes the specific governance structures of rural California education, the single singles, the collapsed county and district offices, the dual reporting requirements, and the funding models designed for larger systems that produce compliance burdens for the smallest. Redwood's account of turning in twelve grant reports simultaneously for two agencies that shared a single staff member pointed toward a policy design failure that no amount of individual organizational capacity could overcome. Policy that requires single-staff county office and district organizations to report as if they were separate entities with separate staffing may need to be redesigned to reflect the governance realities it is meant to regulate.

**Micro Level — Policy Attention to Indigenous Student Equity.** At the micro level, policy must attend specifically to the conditions that produce the systematic underperformance of Indigenous students in rural science education, including the artificial deflation of assessment data produced by testing system designs that do not account for the intergenerational distrust of government institutions that Juniper and Redwood documented. Assessment policy reform that attends to the specific conditions of Indigenous rural communities, including community-controlled opt-in assessment designs, portfolio-based assessment alternatives, and the integration of Indigenous ways of knowing into science assessment frameworks, is consistent with both the findings of this study and the broader calls for epistemological equity in science education documented in the literature.

### *Recommendations for Practice*

**Macro Level — Place-Conscious Rural Science Education.** The third recommendation addresses the practice of rural science education at the school site, district, and county levels and centers on two interconnected practice priorities that the findings of this study identified as the most powerful and the most structurally vulnerable dimensions of equitable rural science education: place-conscious science education and science-based community partnerships for professional learning.

The findings of this study provide what may be compelling evidence for the power of place-based science education as a vehicle for culturally resonant, identity-affirming, and intellectually rigorous science learning for rural minoritized students. The recommendation offered here extends beyond place-based science education as it is conventionally understood, as instruction that uses the local natural environment as a context for science learning, to advocate for place-conscious science education that attends not only to the ecology and geography of specific places, but to the ways in which the people in those locations interact with place, with institutions, and with one another. McHenry-Sorber and Sutherland (2020) described place-conscious leadership as the cultivation of deep awareness of the geographic, cultural, relational, and political dynamics of specific locations and the findings of this study suggest that this same place-consciousness may need to extend to science instruction itself, attending to the colonial histories embedded in place names, the class and racial dynamics embedded in who is seen as belonging to the natural world, and the political conflicts embedded in what counts as scientific knowledge in specific rural communities.

Place-conscious science education, as this study documents it, may mean understanding that the Maidu names erased from the landscape of Plumas County are not merely cultural artifacts but epistemological resources for science learning. It may mean understanding that the student whose grandmother took her to Yosemite is not a passive recipient of place-based instruction but an active knower whose relationship to that place is a foundation to build upon. It may mean understanding that the Latino student whose parents work on a dairy farm brings ecological and systems knowledge to science class that no textbook provides and that honoring that knowledge is not a pedagogical nicety but a scientific and ethical imperative. And it may mean understanding that the political conflicts over science content in conservative rural communities are not obstacles to be navigated around but conditions to be understood, named, and addressed with the same place-conscious awareness that informs every other dimension of rural science education leadership.

This study recommends that place-conscious science education be created, supported, and sustained at the school site level, not as an add-on program or a supplemental enrichment activity but as the foundational curricular orientation of rural science education. The locally authored curriculum of Incense Cedar in Plumas County, the science arts camp of Pine in Mariposa County, the Science Leadership Exchange of Douglas Fir in Trinity County, and the contracted science instructor model of Oak in Siskiyou County were all expressions of this orientation and they represent models that appear to deserve documentation, resourcing, replication, and sustained investment across rural California.

**Meso Level — Science-Based Community Partnerships for Professional Learning.** At the meso level, the findings of this study appear to strongly support the development and sustained investment of science-based community partnerships for professional learning partnerships that bring scientific expertise directly into relationship with classroom teachers in ways that extend the professional learning infrastructure of rural systems beyond what those systems can sustain internally.

The teacher capacity deficit documented in Finding 1.3 appeared structural and persistent and the most effective responses to it documented in this study were not those that waited for the deficit to be closed through formal credentialing or district-level professional development but those that built parallel professional learning infrastructures through community partnerships that placed scientific expertise alongside classroom teachers in the specific places where those teachers worked. The model documented by Incense Cedar, partnering every teacher with a local biologist, hydrologist, or naturalist to provide ongoing mentorship and support, was not a luxury but what appeared to be a necessity in a context where the formal professional learning infrastructure was insufficient. The Watershed Center partnerships documented by Douglas Fir, the NGO networks documented by Incense Cedar, and the science instructor contracting model documented by Oak all represented variations on the same essential insight: that in rural science education, the professional learning infrastructure that teachers needed to deliver equitable science instruction could not be provided by the school system alone and may need to be built through sustained, trust-based partnerships with the scientific and community organizations that share the school's place and mission.

Critically, these partnerships may need to be designed not only to supplement teacher capacity in the present but to sustain it across the staff turnover that the economics of scale in rural educational systems made appear inevitable. The Junction Elementary science unit documented by Oak, a powerful, place-based, inquiry-driven unit created by a second-year intern teacher who then left the profession, illustrated the risk of professional learning investments that were not institutionally embedded in ways that survived individual departures. This study recommends that science-based community partnerships be structured with explicit attention to institutional memory, documenting the curriculum, the instructional approaches, and the community relationships built through those partnerships in ways that can be transmitted to incoming teachers, reducing the degree to which equitable science instruction depends on the specific knowledge and relationships of any single individual. The goal is a rural science education professional learning infrastructure that is relational in its character and institutional in its durability, one that appears designed to ensure students do not receive substandard science education every time staff turnover occurs.

**Micro Level — Leadership Preparation for Rural Science Education.** At the micro level, the findings of this study point toward the preparation of the next generation of rural science education leaders as a critical and currently underaddressed practice priority. Teacher preparation programs should offer opportunities for teacher candidates to learn about rural educational systems and to work within them as a required component of their credentialing. The findings of this study, particularly the accounts of intern teachers placed in multi-grade rural classrooms without adequate preparation, the teachers who appeared never to have been taught how to read a curriculum, and the elementary educators who had avoided science throughout their careers because their preparation programs had not equipped them to teach it, are consistent with what Campbell (1986) identified as the need for specialized rural teacher preparation and what Seelig and McCabe (2021) described as the relational and place-based foundations of rural teacher retention.

Teacher preparation programs should require rural placement experiences as a component of the student teaching and credentialing process, experiences that expose teacher candidates not only to the logistical realities of rural classrooms but to the cultural, historical, and political dynamics of rural communities, the place-conscious pedagogical approaches that rural science education appears to demand, and the community partnership infrastructures that rural science education leadership relies upon. At the leadership level, preparation programs for rural educational leaders may need to develop the specific competencies that the findings of this study suggested were essential, the place-conscious political awareness to navigate conservative community dynamics without compromising equity commitments, the cultural competence to recognize and honor the funds of knowledge that Indigenous and minoritized students bring to science learning, the organizational knowledge to build and sustain community partnerships that extend the professional learning infrastructure of under-resourced rural systems, and the succession awareness to build the next generation of rural science education leadership capacity rather than simply filling the current generation's vacancies.

The retiring leader with over thirty years of rural science education experience who participated in this study appeared to have built a body of knowledge, a network of relationships, and a curricular legacy that represented decades of irreplaceable investment. However, the structural conditions of rural educational leadership appeared not to have ensured that this investment would be transmitted and sustained beyond their tenure. Leadership preparation programs may need to attend to this succession challenge not as an afterthought but as a core competency of rural educational leadership development, ensuring that the next generation of rural science education leaders arrives prepared not only to navigate the structural conditions they will inherit but to transform them.

In summary, this chapter presented the conclusions, discussion, and recommendations of this study, drawing on the full body of evidence produced by both the pilot study and the larger investigation. The conclusions suggested the possible structural, persistent, and compounding nature of the barriers to equitable rural science education; the extraordinary navigational creativity of rural science education leaders operating within those barriers; the apparent underrecognized centrality of Indigenous student marginalization in the rural education equity story; and the possible insufficiency of navigation alone to produce the structural transformation that equitable rural science education may require.

The discussion situated these conclusions within the existing body of scholarly literature, bringing the participant accounts into conversation with the theoretical frameworks of Ray (2019), Young and Arnold (2020), and Ladson-Billings (1995), and connecting those frameworks to one another through an integrated analytical architecture that illuminated how racialized organizational conditions at the macro level appeared to cascade through leadership conditions at the meso level and into instructional conditions at the micro level. The discussion further engaged the work of Thier et al. (2021), Showalter et al. (2023), Grant et al. (2024), Copeland (2013), McHenry-Sorber and Sutherland (2020), Zuckerman et al. (2018), NASEM (2022), Anderson et al. (2018), Lewis-Durham and Saastamoinen (2022), Kirchgasler and Yolcu (2022), Moore (2007), Lee et al. (2021), Hammond (2015), Joubert and Lensmire (2021), Grant-Panting (2021), Aikenhead (2001), Paris and Alim (2014), Ricket et al. (2023), Harmon (2017), Wargo et al. (2021), Campbell (1986), Seelig and McCabe (2021), Anderson and Herr (1999), and Crain (2023) — identifying where the findings of this study appeared consistent with, extended, and in some cases complicated the existing scholarly conversation.

The synthesis surfaced four cross-cutting interpretive possibilities: the continuing and compounding nature of the struggle, the distinctive markers of rural educational leadership as structural conditions, political conflict as a possible structural feature, and the possible underrecognized centrality of indigenous student marginalization and concluded with the observation that navigation may not be transformation, and that the recommendations of this chapter must be directed toward the structural transformation the evidence appears to demand. The recommendations offered across research, policy, and practice at the macro, meso, and micro levels, centered on place-conscious rural science education and science-based community partnerships for professional learning as the two practice priorities most powerfully supported by the evidence constitute a call not for incremental improvement but for the coordinated, structural, and sustained response that the students of rural California and the leaders who have fought for them have long deserved and have not yet received.

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Appendix A

UNIVERSITY OF CALIFORNIA AT BERKELEY

BERKELEY DAVIS IRVINE LOS ANGELES MERCED RIVERSIDE SAN DIEGO SAN FRANCISCO SANTA BARBARA SANTA CRUZ

**Research - Interview Protocol**

***A Preliminary Inquiry into Understanding Rural Education Leader Intentions for Supporting Minoritized Students in Science***

**Purpose of the Study:** The purpose of this study is to learn the ways in which rural science education leadership is preparing to respond to the needs of minoritized students in their communities.

**Overarching Research Question**

1) How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?
2) What system barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?

**Introduction:**
Hello, ___. Thank you for taking time to help me with my study. I'm at UC Berkeley, in the Leaders of Equity and Democracy doctoral program. I am studying how rural science education systems leaders respond to the needs of minoritized students.

**Interviewer:** Rosanna Ayers

**Interviewee:** What is your current organization and title? What was the organization and title of your position just prior to this position?

**Interview Questions**

1. Tell me a little about the student science performance in your rural school.
   a. *What trends have you observed in student science performance data?*
   b. *Are there any notable differences among student groups?*

2. Which students would you say are minoritized or marginalized in your system?
    a. *What would you say are the approximate racial demographics of your student population?*

3. When thinking about what the data say about the science performance of particular student populations?
    a. *What data are you considering?*
    b. *What does the data show?*

4. What policies/practices have you seen put in place to support minoritized/marginalized students?
    a. *The policies/practices might be at a classroom level, school board level, school site level and/or state level.*
    b. *How effective do you think these policies have been in practice?*

5. What are some system tools that your district/county uses to move from policy to practice with supporting minoritized/marginalized students?
    a. *Are there any gaps between policy and actual classroom implementation?*

6. What are some things you've had to navigate in bringing science to rural minoritized/marginalized students?
    a. *Can you describe any challenges you've encountered in ensuring equitable science education for minoritized students in your district?*
    b. *Can you describe any opportunities you've discovered in ensuring equitable science education for minoritized students in your district?*

7. Tell me a story about a great science outcome from a minoritized student in your school/district. And what contributed to that successful outcome?

8. Is there anything else you think I should know about how rural science education leaders, like yourself and others, are supporting minoritized students?

Thank you so much for participating, I really appreciate your willingness to share your experiences.
END
Appendix B

UNIVERSITY OF CALIFORNIA AT BERKELEY

BERKELEY DAVIS IRVINE LOS ANGELES MERCED RIVERSIDE SAN DIEGO SAN FRANCISCO SANTA BARBARA SANTA CRUZ

**Informed Consent Form**

***A Preliminary Inquiry into Understanding Rural Education Leader Intentions for Science Instruction for Minoritized Students***

**Key Information**

- You are being invited to participate in a research study. Participation in this research is completely voluntary.
- The purpose of the study is to understand how rural educational leaders are preparing for and implementing science instruction, recommendations as described in NGSS and other documents, for minoritized students.
- The study is a qualitative case study design inviting participants to individually share their experience in a 45 minute interview conducted via zoom. A follow up email or zoom call might be requested to clarify responses.
- Risks or discomforts may include minimal distress when reflecting on your own experiences related to science education for minoritized students.
- There is no financial compensation for participation.
- The results from the study may help inform rural educational leaders who are tasked with implementing science instruction, recommendations as described in NGSS and related documents, at their school sites.

**This form is to be read to participants to make sure they are fully aware of their rights and privileges.**

**Introduction and Purpose**

My name is Rosanna Ayers and I am an instructor at the University of California Merced Teacher Preparation Program and a student at the School of Education at the University of California, Berkeley. I would like to invite you to take part in my research study, which aims to understand rural education leaders' intentions to provide NGSS-aligned science instruction to minoritized students in the school sites. This research is carried out under the supervision of faculty advisor, Dr. Michelle Wilkerson of University of California Berkeley, School of Education. Currently, rural school districts enroll 1 in every 7 students in the US (Showalter, D., Hartman, S. L., Eppley, K., Johnson, J., & Klein, B., 2023). The focus of this research is on rural leaders' (administrators, superintendent, assistant superintendent, curriculum and instruction and/or teachers leader) experiences with school or district wide implementation of NGSS with special attention paid to these leaders' decision making as it relates to minoritized student access and support.

**Procedures**

If you agree to participate in my research, you will be asked to do the following:

Participate in an online, one on one interview of questions.

*Total time:* The interview is designed for 45 minutes but may take up to 60 minutes depending on the length of participant responses.

*Study location:* The study will be completed online on a UC Berkeley-administered Zoom account. You are encouraged to sign onto the online meeting invitation in a fairly quiet location with reasonable privacy.

**Benefits**

There is no direct benefit to you from taking part in this study. An indirect benefit might be that the research will help to raise an awareness of the impact that access to state funded equitable science instruction has on marginalized rural students.

**Risks/Discomforts**

Some of the interview/survey questions might make you feel uncomfortable or upset. You are free to decline to answer any questions you do not want to, or stop the interview at any time.

As with all research, there is a chance that confidentiality could be compromised. As the interview will be held online, the nature of an interview is such that confidentiality cannot be guaranteed. However, I am taking precautions to minimize this risk. I will treat all discussion and information shared during the interview as confidential.

**Confidentiality and Data Protection**

Your study data will be handled as confidentially as possible. If results of this study are published or presented, individual names and other personally identifiable information will not be used.

A zoom recording will be created. Participants will turn off their videos during interviews. To minimize the risks to confidentiality, we will transcribe the audio recordings within one month of the interview. Investigators' notes and transcriptions will have identifiers removed and replaced with a code. We will remove identifiers from the data and replace them with codes linking the data with the identifiable information. Investigators will maintain a key that links the codes to identity and store the key in a password protected and encrypted folder in UC Berkeley administered, secured cloud storage. When the research is completed, I will save the transcriptions and other study data for possible use in future research done by myself or others. Identifiable data, including the key that links codes to identifiers, will be retained for up to three years after the study is over. De-identified data will be retained indefinitely for possible use in future research done by ourselves or others.

Your personal information may be released if required by the law. Identifiers will be removed from the identifiable private information. After such removal, the information could be used for future research studies or distributed to other investigators for future research studies without additional informed consent from the subject or the legally authorized representative.

**Compensation**
While your participation is greatly appreciated, there is no compensation available for participation in this important study.

**Rights**
***Participation in research is completely voluntary***. You are free to decline to take part in the study. You can decline to answer any questions and are free to stop taking part in the study at any time. Whether or not you choose to participate in the research study, choose to answer any questions or choose to participate in the study, there will be no penalty to you or loss of benefits to which you are otherwise entitled. Whether or not you decide to participate in this research will have no impact on your employability or standing at your school or school district. Participants can withdraw without providing a reason.

**Questions**
If you have any questions about this research, please feel free to contact me, Mrs. Rosanna Ayers at rjayers@berkeley.edu. This research has been approved by UC Berkeley Institutional Review Board IRB #00006252. If you have any questions about your rights or treatment as a research participant in this study, please contact the University of California at Berkeley's Committee for Protection of Human Subjects at 510-642-7461, or email subjects@berkeley.edu.

**Reference**
Showalter, D., Hartman, S. L., Eppley, K., Johnson, J., & Klein, B. (2023). Why Rural Matters: *Centering Equity and Opportunity*. National Rural Education Association. https://www.nrea.net/why-rural-matters

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**CONSENT**
If you agree to participate in this research, please email Rosanna Ayers at rjayers@bekeley.edu of give verb

Appendix C

UNIVERSITY OF CALIFORNIA AT BERKELEY

BERKELEY DAVIS IRVINE LOS ANGELES MERCED RIVERSIDE SAN DIEGO SAN FRANCISCO SANTA BARBARA SANTA CRUZ

November 19, 2025

The Five Essential Science Leadership Functions are critical job functions developed in collaboration with the California County Superintendents, CISC (Curricular and Improvement Support Committee) Science Subcommittee Chair and reflect the essential roles of a science education leader recognized by the statewide CISC Science Subcommittee.

The five essential functions or roles are:

1. Provides or selects Professional Learning
2. Disseminates information from CDE and State Board of Education back to local LEA
3. Elevates contextualized needs of LEA to CDE and State Board of Education
4. Plans and implements science related events for LEA
5. Advocates to the LEA a need for public science education

Rural education leaders who perform any **3** of the essential functions would be designated as a rural science education lead for the purposes of this research.

CDE - California Department of Education
LEA - Local Education Agency

**Appendix D**

| Rankin g | The Public Policy Institute of California (PPIC) notes that six California counties are entirely rural (i.e., nearly all population is in rural blocks) |
|---|---|
| | Most Rural in descending order. |
| 1 | Alpine County |
| 2 | Mariposa County |
| 3 | Modoc County |
| 4 | Plumas County |
| 5 | Sierra County |
| 6 | Trinity County |
| | Additional rural-designated counties in California (beyond the six entirely rural ones) as referenced in policy sources. (PPIC) |
| 7 | Amador County |
| 8 | Calaveras County |
| 9 | Lassen County |
| 10 | Siskiyou County |
| 11 | Tehama County |
| 12 | Inyo County |
| 13 | Mendocino County |
| 14 | Mono County |
| 15 | Del Norte County |
| 16 | San Benito County |
| 17 | Glenn County |
| 18 | Colusa County |
| 19 | Tuolumne County |
| 20 | Lake County |
| 21 | Shasta County |
| 22 | Madera County |
| 23 | Humboldt County |
| | Using published RCTF/related sources, three counties missing from my earlier combined list that appear among the rural-designated counties: |
| 1 | El Dorado |

| | |
|---|---|
| 2 | Kings County |
| 3 | Sutter County |

**Appendix E**

**Findings Overview Chart**

RQ1-What system barriers do science educators face in aligning NGSS instructional practices to the needs of minoritized students?

RQ2-How do rural science educational leaders navigate the complexities of supporting the needs of minoritized students in science education?

| | | |
|---|---|---|
| **Systemic Barriers** | Finding 1.0 | System constraints on rural leaders support of science education |
| | Finding 1.1 | De-prioritization of science in rural education through lack of accountability |
| | Finding 1.2 | Economics of scale in rural educational systems |
| | Finding 1.3 | Limited rural teacher capacity building in science content and pedagogy |
| **Cultural and Historical Barriers** | Finding 2.0 | Limited rural educator cultural competence with minoritized/marginalized students |
| | Finding 2.1 | Historical challenges to science instruction for the rural school |
| | Finding 2.2 | Social and/or professional class divide amongst communities |
| **Navigation to increase access** | Finding 3.0 | Brokering science access for marginalized students |
| | Finding 3.1 | Place-based science leadership/ instruction to provide science instruction support |