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Understanding the Priorities and Practices of Rural Science Teachers: Implications for Designing Professional Learning

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Research Article

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In order to design professional learning that supports rural science teachers to effectively implement standards-based "five-dimensional" (5D) instructional and assessment practices, a critical first step is to elicit their perspectives, prior experiences, concerns, and interests. Based on survey data from 87 rural science teachers in Colorado, along with focus group sessions with 18 of those teachers, this article investigates teachers' perspectives on what makes rural science teaching unique, the degree to which they use 5D science instruction, their curricular and assessment resources, and their professional learning experiences and preferences. Overall, rural science teachers in Colorado reported using rich practices for engaging students' interests and identities in the pursuit of high-quality engagement, and they expressed a need for more science-specific professional learning and materials distribution. Implications for designing professional learning opportunities for rural science teachers are offered.

Systems of science education in the US have begun to shift toward a vision that includes three dimensions (3Ds): science and engineering practices, crosscutting concepts, and disciplinary core ideas (SEPs, CCCs, and DCIs) in the domains of physical science, earth and space science, life science, and engineering and technology (NGSS Lead States, 2013). Central to this vision is the principle that students must make sense of science in a 3D manner that integrates the SEPs, CCCs and DCIs. A major goal for this shift is to more equitably distribute high-quality opportunities to learn science to historically underserved communities (NRC, 2012), although the Next Generation Science Standards have been criticized for not adequately forefronting issues related to access and equity (e.g., Rodriguez, 2015).

In response to such critiques, researchers have highlighted the importance of engaging in science instruction that reflects a deep understanding of the sociocultural identities, ideology, and practices of local communities (Bang et al., 2016; Morales-Doyle et al., 2019). In particular, Bell (2016, 2019) has argued for the inclusion of student interest and identity as two additional dimensions that, together with the SEPs, CCCs, and DCIs, comprise a five-dimensional (5D) framework for improving K-12 science education. Leveraging students' diverse identities along with their interests in specific scientific phenomena is an important way to build meaningful learning and help students see "practice-linked" connections between themselves and science (e.g., Nasir & Hand, 2008; NRC, 2009). Additionally, the Framework for K-12 Science Education asserts that interest and identity are critical for engaging sociocultural components of learning such as home-to-school connections, community priorities, and students' perceived relevance of units of study (NRC, 2012). See Table 1.

Table 1
Components of 5D Science Instruction (NRC, 2012)

Science and Engineering Practices	Behaviors that scientists and engineers use as they investigate the world and solve problems.
Crosscutting Concepts	Ideas that link all domains of science, such as patterns
Disciplinary Core Ideas	Core domains of science thinking, including physical science, earth and space science life science, and engineering and technology
Interest	Motivation that leads to engagement in science instruction
Identity	The life experiences and positions that students bring to science learning

Almost all research and improvement efforts for interest and identity-linked science learning have taken place in urban and suburban communities which have greater access to researchers, research funding, universities, coursework, state leaders, and nonprofits dedicated to improving science education. This has led to what Zinger et al. (2020) term “urbanormativity” (p.14). Consequently, very little is known about how to support 5D science education and its implementation in rural schools. One-third of American public schools are rural and one in five students attends a rural school (Showalter, Hartman & Johnson, 2019; Williams, 2010), yet there is a lack of understanding of the current state of science instruction in rural schools and, therefore, little research to guide its advancement.

Despite the lack of attention devoted to understanding standards implementation in rural schools and districts, rural contexts have rich potential as places where 5D science learning can take root (Avery, 2013). In particular, the place-based experiences of rural students are assets for educators to build on and researchers to learn from (Long & Avery, 2017). While they have not investigated 5D specifically, several scholars articulated the connections students can make with local places (e.g., Eppley, 2017; Zimmerman & Weible, 2017), and how students can use science as a tool to advocate for improvement in their rural communities (Huffling et al., 2017; Zimmerman & Weible, 2017). These findings highlight the deep understandings of place held by rural students and their communities, and the potential to leverage place-based interests and knowledge alongside other assets to make science learning more meaningful and expansive. Further, this advocacy may improve the quality of rural life for current and future residents, as students fight for cultural recognition, political representation, the equitable distribution of resources, and sustainable usage of land (Bang et al., 2016).

Empirical and theoretical work that highlights the unique assets of rural science students, teachers, and their communities (e.g. Avery & Hains, 2017; Borgerding, 2017; Kassam et al., 2017; Oliver & Hodges, 2104) suggests that rural contexts could provide what is currently an underutilized engine for innovation in 5D science learning. Harris and Hodges (2018) assert that “rural schools represent mostly untapped potential” (p. 10), noting that although rural students perform similarly to non-rural students on a wide range of educational outcomes and achievement measures, they are less likely to pursue STEM careers. Shifting science classrooms to become 5D and driven by fostering interest and identity may be particularly important for achieving equity in access to science careers for rural students compared to their urban peers.

The Need for 5D Professional Learning Targeted for Rural Science Teachers

Despite the potential for place-linked, 5D science pedagogy, very little literature examines the possibilities for professional learning (PL) that directly supports rural educators. Rural teachers are less likely to receive PL workshops and support—particularly in student-centered modes of instruction—than their urban and suburban counterparts (Avery & Kassam, 2011; Banilower et al., 2018). Yet the evidence for high-quality, sustained professional learning is clear in science implementation literature. Without PL, teachers are less likely to be able to help their students make rich connections between science and their everyday lives (Avery & Kassam, 2011; Chinn, 2012). As demographics of rural areas continue to become less white, the decreased resources in rural areas take on a racial and cultural component (Long & Avery, 2017), and care must be taken that students’ racial or socioeconomic status are not predictive of their science learning opportunities (NRC, 2012). While studies show that rural educators are resilient to the lack of resources (Showalter et al., 2019; Zimmerman & Weible, 2017), they desire science-specific PL that focuses on high-leverage practices for implementing the Next Generation Science Standards. A recent survey of 86 rural science teachers in Colorado found the vast majority are eager for PL that can help them learn to support students in the practices of explanation (92%), developing and using models (86%), and designing and testing solutions to problems (80%) (Wingert & Penuel, 2019). Further research may illuminate the motivations, visions, and professional learning practices of science educators working in rural settings.

Using Teachers’ Perspectives to Guide Professional Learning

This study is situated within a larger design-based implementation research project (Fishman et al., 2013) aimed at building professional learning targeting teachers in rural communities that historically have unequal access to research-driven, affordable, science-specific resources (Glover et al., 2016). This PL includes supporting educators to build assessments that engage the interests and identities of their students while being strongly aligned to the practices, core ideas, and crosscutting concepts included in the state standards. Prior to developing an ambitious PL effort of this nature, a critical first step is to elicit teachers' perspectives, prior experiences, concerns, and interests so as to refine the goals for joint work. This study investigates how rural science teachers report engaging their students in science and engineering practices, disciplinary core ideas, and crosscutting concepts that align with students' interests and identities, as well as the supports and constraints they encounter in the pursuit of equitable 5D instruction. Our research questions are: (RQ1) What makes rural science teaching unique?, (RQ2) To what degree do rural teachers report 5D science instruction?, (RQ3) What curricular and assessment resources do rural science teachers use?, and (RQ4) What are rural science teachers' PL experiences and preferences?

Context

This study took place in Colorado, a large state in the Rocky Mountain region of the United States. The study began within a year of passage of the state's first 3D science standards that closely match the Next Generation Science Standards (NGSS Lead States, 2013). Much of Colorado is mountainous and snowy, with restricted travel possible from November-May. The geography of the state makes extensive professional learning difficult for rural educators, as many communities and families are without reliable home internet. The state also has several loosely connected professional organizations that do not systematically communicate, share resources, or provide wide-reaching teacher learning. Regional offices supporting rural school districts focus on providing services that are legally required but too expensive for small schools to offer themselves, such as school psychologists, speech therapists, or other specialized services that occasionally include STEM education support.

Methods

The research team constructed a survey consisting of 42 questions (some of which contained sub-questions) organized into six sections: (1) pedagogy aligned with the state science standards, (2) promoting equity, interest and identity, (3) teaching in a rural context, (4) teachers as learners, (5) PL design considerations, and (6) school and teacher demographics. All of the questions were closed-ended except for three open-ended questions asking teachers about their community and school context. Cognitive interviews conducted prior to finalizing the survey ensured that the questions were worded appropriately and readily understandable and suggested that the estimated time required to complete the survey was 15 minutes.

In order to gain perspective from as many rural Colorado teachers as possible, the research team used a purchased email list of K-12 science teachers in the state to generate a data sample. We filtered the list by schools designated as "rural" by the CO Department of Education, which yielded approximately 400 valid teacher emails. (The state classifies communities as "rural" in terms of their distance from a city.) Out of the teachers who were emailed, 87 (22% response rate) took the survey and 65 completed every question. Because we are not using the survey for statistical comparison, we did not remove incomplete results. We do not make claims about how representative the data are, but the sample demographics presented provide us with perspectives from a wide range of rural educators.

Table 2 displays the participants' demographic information. Teachers who responded to the survey had extensive teaching experience. A large majority had taught for five or more years, with the average being 12.14 years (SD = 7.81) at their current school, and a range of 0-36 years. Only one teacher said they were not fully certified to teach all of their course load, which is evidence of a very highly qualified sample of teachers in rural schools in terms of national certification requirements (e.g., ESSA). Additionally, the teachers taught numerous science courses across many grades; in fact, some teachers taught grades 7-12 all in the same year. Of the secondary teachers, very few taught only one grade level and many taught more than three grade levels. The courses taught were varied, and the most frequently selected answer was "other". Teachers wrote in AP courses, environmental science courses, forensics, zoology, and anatomy/physiology, among others.

The teachers worked at schools that varied in size. A third had graduating sizes of less than 60 students, 44% had graduating classes of 60-149 students, and none had more than 300 students. Six teachers reported graduating classes of less than 20. Four were the only science teacher in their buildings, but most had robust science departments of four or more teachers.

We asked surveyed participants if they were willing to take part in a 90-minute focus group session,

Table 2
Participant Demographics Summary

	% of all survey respondents	n	*% of all focus group participants*	n
Total Respondents		*65*		17
Race/ Ethnicity Self-Identification				
White/ Caucasian	84.60%	55	82.35%	14
American Indian/Alaska Native	0	0	0	0
Asian/Asian American	1.54	1	0	0
Black/ African American	0	0	0	0
Hispanic/ Latinx	3.08	2	5.88	1
Native Hawaiian/ Pacific Islander	0	0	0	0
Other	1.54	1	0	0
Prefer not to answer	9.23	6	11.76	2
Gender Self-Identification				
Male	29.20	19	0	0
Female	69.23	45	100	17
Prefer not to say	1.54	1	0	0
Years Teaching				
0-4	6.15	4	5.88	1
5-14	27.69	18	35.29	6
15-24	43.08	28	41.18	7
25+	18.46	12	17.65	3
Highest Education Level				
Bachelor’s	24.6	16	11.76	2
Bachelor’s plus graduate coursework	3.1	2	0	0
Master’s	69.2	45	82.35	14
Doctorate	1.5	1	5.88	1
Grades Taught 2020-21*				
K-5	16.9	11	5.88	1
6-8	24.6	16	47.06	8
9-12	50.8	33	52.94	9
College credit	3	5	11.76	2
Courses Taught				
Elementary				
Elementary science	8.90	13	5.88	1
Middle School				
Integrated middle-level science	2.70	4	11.76	2
MS Life Science	6.16	9	17.65	3
MS Physical Science	6.16	9	17.65	3
MS Earth & Space Science	6.16	9	29.41	5
High School				
HS Earth & Space Science	7.53	11	23.53	4
HS Physical science	8.22	12	23.53	4
HS Physics	8.22	12	17.65	3
HS Biology	14.38	21	35.29	6
HS Chemistry	15.07	22	29.41	5
Other	16.44	24	58.82	10

conducted remotely, to delve further into issues related to their local context, current instructional and assessment practices, curricular decision making, and PL suggestions. Seventeen teachers participated in a focus group session. Teachers were organized into 6 focus groups, with 3-5 teachers in each group. Each group met one time, approximately three weeks after administering the survey. The focus groups targeted the following topics: pedagogy aligned with the state science standards; the role of assessment in classroom instruction; promoting equity, interest and identity; and PL design considerations. Each meeting was audio recorded and transcribed. The focus group participants were all female and the majority were white/not Hispanic, held a Master's degree, and taught at the secondary level (see Table 2).

The survey and focus groups generated both categorical and qualitative data that we analyzed thematically. The focus group transcripts and open-ended survey questions were coded using an inductive process to identify relevant themes. We grouped our data by research question and drew from survey and focus group information to address each question. For example, survey questions about context and focus group responses having to do with specific rural issues are presented together to answer the question "What makes rural science teaching unique?" We member-checked the findings with several state leaders to ensure our understanding of local implementation and concerns was accurate.

Findings

RQ1: What Makes Rural Science Teaching Unique?

Affordances of teaching in rural schools. The survey included an open-ended question asking teachers what they enjoy about teaching in rural schools that people designing PL should know. The main affordances teachers brought up were being part of a close-knit community and having small classes (>50%). Three teachers mentioned enjoying the intergenerational community they served, including working with students and potentially those students' children. A few explained how rewarding this experience can be and how it can support engaging, practical science instruction, such as this teacher who wrote:

> It is a small community. I have 30 students that are broken into two sections and so I really get to know my students, their lives, interests, their families. This helps my instruction as I am able to make direct connections to their lives. We are currently learning the water cycle & watersheds in science. There are a lot of ranching families, and I am able to make direct ties about water usage in Colorado to their livelihoods and ranching. In the future, I hope to do more investigations with the students that directly tie into their lives and interests--an achievable goal because I know them so personally.

Eighteen surveyed teachers emphasized the presence of outdoor opportunities to support their science curriculum. Several teachers who wrote about the outdoor experiences their students have access to mentioned that they connect meaningful science learning opportunities with the natural environment, including going to local rivers or engaging with local wildlife or forestry/fire management. One teacher explained that living in a rural mountain setting offers students access to unique outdoor resources that are very different from those that may be available to their urban and suburban counterparts:

> Students in my rural community have less access to some resources (museums, big libraries, large district resources, often family education level is lower than in less rural communities), but more access to going outside - down by the river or into the forest near the school for hands-on science in the field. Also, many of my students lack formal education, but have experiences on ranches, farms, hunting, camping, hiking, etc. that represent a large amount of prior knowledge that just needs to be pointed in an academic direction. For example, probably 1/3 to 1/2 of my 10-11 year old students have seen a mountain lion in the wild...how common is that?!?!?

Challenging aspects of teaching in rural schools. Surveyed teachers reported that financial constraints and limited other resources to support new populations of students are among the most challenging aspects of working in rural schools. Specifically, teachers mentioned a lack of materials and financial resources (n=16) and an increasing emerging multilingual population to differentiate for in their classes (n=9). In addition, 14 teachers expressed that the conservative political context in some of their communities can make certain parts of science instruction challenging. To a lesser extent, teachers wrote about the unreliability of rural internet (n=5), having multiple courses to prepare for (n=4), feeling like they had no one to collaborate with (n=3), and the difficulties in being remote in the 2020 school year due to COVID-19 (n=3).

Teachers also mentioned the complexity of balancing their roles as science educators with the belief systems prevalent in their rural communities, which can sometimes cause tensions. Across surveys (n=4) and focus groups (n=3), a number of teachers shared that it was very important for professional developers to understand the conservative political contexts of their communities, and the implications for science curricular issues such as climate change, evolution, and vaccines. A first-year teacher talked about how she had to do "a dance" to keep science as a discipline separate from the belief systems held by members of her community:

> Because of the conservative nature of the community, I am mindful how I present certain social justice issues. In my elective, Environmental Education, I touch on environmental justice. However I need to be mindful of how I am presenting this information. A co-worker recently told me that we need to make clear to the students we are not indoctrinating them, but rather making it clear that we are teaching them how to think critically. This is how I try and be mindful...how to present the information that in the end is about critical thinking and understanding problems without passing judgement of right/wrong to them.

Similarly, another teacher described their role within their conservative community as one that requires care when confronting students' anti-scientific ideas, "I don't think it is professional to discredit their belief system (the earth is flat, climate change is fake, vaccines are fake, etc)." These responses suggest that efforts to support rural teacher leadership should take into account the complex roles science teachers take on as they attend to teaching in a manner that is both non-confrontational and that introduces important scientific ideas to the community.

RQ2: To What Degree Do Rural Teachers Report 5D Science Instruction?

Attending to the standards. During the focus groups teachers expressed that they were attending to 3D standards to at least some degree in their instruction, and more specific survey questions were able to tease apart the presence of science and engineering practices in the respondents' classes. Overall, most teachers reported some efforts to align instruction to the standards, but modeling and engineering practices, two key aspects of the 3D vision, did not appear to be widely used.

Several teachers stated confidently in the focus groups that their instruction was closely aligned to the state standards, largely due to the fact that they were following NGSS-aligned curriculum, had taken part in extensive PL efforts, and/or had already made a concerted effort to shift their teaching for the past several years. For example, Elizabeth[1] explained:

> We as a department looked at the new [Colorado] standards. They really are 99% the exact same as the NGSS. So there wasn't a lot of professional development or opportunity to really dig deep and to understand them, because we have done that for the last nine years, essentially, when NGSS came out.

Similarly, Marge noted: "I've been looking at NGSS for a long time...A lot of my professional development through Summit Learning in their organization has been the best connection to how NGSS really works." Neither of these respondents described specific shifts other than using aligned materials.

Most of the focus group teachers said that they were moving toward incorporating the standards into their practice. These teachers talked about using phenomenon-based instruction, focusing on student inquiry, and shifting to 3D assessments. Teachers often noted that they were still in the learning phase of this shift and shared ways that they were actively seeking to gain knowledge and acquire resources. Mel described her school's effort to shift their assessment practices to become better aligned: "It's more about the assessments, we've been trying to target and shift a little bit more, and make it instead of just everything being multiple choice... shifting and trying to incorporate more project-based learning into the assessments."

A few focus group teachers reported no serious efforts to align their instruction to the standards, echoing their lack of interest in seeking out aligned curriculum. Some of these teachers explained that they were teaching new classes or classes that were more difficult to align, while others were simply not attending to the standards overall. For example, Emily candidly portrayed her predicament:

> I just started teaching biology this year. And I really don't know what I'm doing. Because I had one day to be ready to teach for biology….I'm meeting some of the biology standards, I'm sure not all of them because the previous teacher did not leave her scope and sequence...And they're based on the old standards, but I'm like it's something that I have to follow.

Teachers' Reported Frequency of Specific Science Practices

Whereas teachers' reports in the focus groups help shed light on their implementation of the standards in a broad sense, the survey data provides a sense of their day-to-day use of specific NGSS practices. Teachers responded to a sequence of closed-ended survey prompts with the stem, "How

[1] All proper names used for teachers are pseudonyms.

often do the following occur in your science classes". They rated each prompt based on whether it occurred "not at all", "monthly," "weekly," "every few days," or "daily." We organized results based on frequency to highlight patterns in their practices (see Table 3). The three most frequently occurring practices teachers reported using every few days or daily were explaining reasoning, supplying evidence, and working together to figure out science ideas (69%, 70%, and 52% respectively). The least common activities all related to modeling and engineering. A majority of teachers (52%) indicated that they engaged their students in engineering monthly or not at all. Similarly, modeling activities were less frequent, including using models to predict outcomes, continually revising models, and physical and conceptual modeling. However, the vast majority of teachers reported that they included modeling activities in their sciences classes at least some of the time. Overall, these data suggest that practices that are newer to the *Framework* (modeling, engineering) are less commonly implemented in rural science teachers' lessons.

Attending to student interest and identity in science teaching. In general, surveyed teachers reported high student interest and engagement in science class activities and topics. For example, the vast majority said "most" or "almost all" of their students were "engaged in the activities we do during science class," (94%), were "interested in the topics explored during science class" (76%), and "see connections between what they are learning in science class and their everyday lives" (75%). This is hopeful; the teachers seemed able to build topical relevance and connections for students that held their interest and supported sustained engagement.

On the other hand, teachers expressed concern that most of their students were not developing scientific identities or connecting their out-of-school activities to science. Only eight teachers reported that almost all of their students saw themselves as scientists in science class and only one teacher responded that almost all of their students seek out science learning outside of class. Focus group teachers communicated that attending to students' interests and identity in their science classes is an equity-focused endeavor that they deem important. Most teachers reported that they were driven by a personal philosophy in pursuit of equity and that they were actively working to support historically

Table 3
Reported Frequency for Survey Prompts with the Stem, "How often do the following occur in your science classes?"

Stem	*M*	*SD*	*Not at all*	*Monthly*	*Weekly*	*Every few days*	*Daily*
Explain the reasoning behind an idea.	3.84	0.76	0%	4%	26%	51%	18%
Supply evidence to support a claim or explanation.	3.76	0.76	0%	7%	24%	57%	13%
Work together to figure out important science ideas.	3.55	0.92	3%	7%	39%	36%	16%
Make an argument that supports or refutes a claim.	3.41	0.81	1%	8%	49%	33%	9%
Revise explanations as they gain new partial understandings of core ideas over time.	3.27	0.7	1%	5%	64%	24%	5%
Critically synthesize information from different sources (i.e., text or media).	3.26	0.77	3%	8%	54%	32%	4%
Ask questions that they will investigate in class.	3.25	0.86	1%	17%	43%	32%	7%
Consider alternative explanations.	3.20	0.8	4%	9%	53%	32%	3%
Use models to predict outcomes.	3.11	0.76	4%	12%	53%	31%	0%
Continually revise models, explanations, and claims during a unit.	3.05	0.86	5%	16%	50%	26%	3%
Respectfully critique other students' reasoning.	3.04	0.87	5%	17%	49%	26%	3%
Create a physical model of a scientific phenomenon (like creating a representation of the solar system).	2.93	0.68	3%	18%	62%	17%	0%
Develop a conceptual model (not provided by textbook or teacher) based on data or observations.	2.80	0.89	7%	31%	40%	21%	1%
Design, test, and evaluate solutions to engineering problems.	2.50	0.97	14%	38%	33%	12%	3%

excluded groups in STEM such as girls, lower SES and homeless students, first generation immigrants, indigenous students and students identifying as LGBTQ+. Generally speaking, the teachers placed a strong value on ensuring that their students not only succeed in science class, but understand why learning science is important and relevant to their lives and their community. As Beth put it, “The history of science is told in a way that's very dead-white-male-centric, so I'm trying to educate myself on some of the contributions of people from other cultures, other socioeconomic classes, and LGBTQ folks.”

A few teachers remarked in focus groups that they make an effort to actively counter racist or sexist beliefs held by some members of their community and occasionally expressed by students in their classrooms. These teachers felt that, as rural educators, it was their responsibility to expose students to a more equitable way of thinking. Sheila communicated this challenge by explaining,

> A big thing that's coming out in Colorado now is about how you teach tolerance in the science classroom. Coming from a rural community where you are 90 plus percent white and people are 90% conservative…. Some of these kids come from families where there’s systemic racism. It's amazing to me that I have kids in my building that think women shouldn't vote….So you try to give them exposure to as many different things… that kind of open up their minds.

Tess was also concerned about discrimination among her students, but expressed less confidence in her ability to mitigate it and raised several questions including, “How do I teach more culturally relevant or like culturally sensitive but inclusive science curriculum? Because...racism, sexism, homophobia, it's in the classroom. And how do we...start to have those social justice conversations in science?” The teachers’ comments during focus groups suggested that they were concerned about interest, identity and equity and had ideas about classroom approaches to ensure wider participation in science. However none of the teachers directly connected these issues to the new standards’ implementation or assessment practices.

Use of practices that support students’ interests and identities. Overall, rural science teachers reported relatively sparse use of classroom practices that would support the development of their students’ science interest and identity as scientists. On average, practices related to interest and identity were far less frequently reported than practices related to science and engineering practices (SEPs). The most commonly reported interest and identity affirming practice was helping students figure out things on their own rather than giving them the answers, which 76% of survey respondents said occurred most classes or every class. Practices most teachers used at least sometimes included ensuring that students understand the “why” behind what they are doing, eliciting student contributions, and “using their ways of speaking, knowing, acting, and valuing to make sense of the world.” Interestingly, despite being deeply appreciative of and caring towards their rural communities, using practices that support students to “connect their home and school ways of knowing” were not commonly reported.

At the same time, teachers who participated in the focus groups generated multiple examples of practices that affirm their students’ interests and identities, despite the fact that surveyed respondents’ use of such practices was infrequent. Focus group teachers highlighted their use of relevant and interesting phenomena, hands-on activities, doing investigations, and project-based learning. Marge talked about providing students with choices, especially when doing projects: “We try to incorporate as much personal choice and perspective into the projects as we can. So that allows kids to kind of go where they want with it. And that tends to increase our engagement.” Jamie argued that students should always think of themselves as scientists during science class: “I think it's important now, every day in science, to just remind them that they are a scientist....Any time you're observing the world or just even thinking about the world around you, you are a scientist. And I think it's important to encourage that thinking.”

During the focus groups, teachers also shared ways in which they organized collaborations between their students and the broader scientific community. These efforts included meeting with local experts, taking field trips, bringing in parents or former students to talk about their careers, and providing students with international experiences. Katie described connecting her students with scientists remotely: “I’ve done quite a bit of set up with Skype a Scientist. So I can connect my kids with scientists around the world who are doing really neat things. Getting the chance to talk with scientists and see what scientists look like. And that they are really just normal people.” Clearly, these teachers are striving to support the development of students’ interests and identities and indicated a variety of possibilities about what such practices can look like.

RQ3: What Curricular and Assessment Resources Do Rural Science Teachers Use?

Teachers' use of standards-aligned curriculum. Teachers reported using a large variety of curricular materials in their classrooms, with different degrees of attention to current science standards. Survey responses about the specific science curricula currently in use in their classrooms generated a long tail. The most frequent responses were "other," "various internet searches/social media", and "I write my own" (n = 45). Some of the more commonly mentioned curricular materials were POGIL (n=14), McGraw Hill (n=12), NextGen Storylines/OpenSciEd/inquiryHub (n=8), Science Fusion (n=3), Discovery (n=3), Pearson (n=3), Summit Platform (n=3), and Prentice Hall (n=3). However, independent review (Edreports.org, 2019) has found that only one in use by the rural science teachers surveyed, Houghton Mifflin Harcourt's Dimensions series, partly meets expectations for design and scope and sequence for middle school science in line with *A Framework for K-12 Science Education*. Two other curricular materials listed by the teachers (OpenSciEd and inquiryHub) had units determined to be of high quality based on an independent review process conducted by Achieve (Achieve, 2014). This means that a large majority of the surveyed teachers indicated a different understanding of "alignment" than what the EdReports.org survey showed. Indeed, most seem reliant on their own capacity to author, edit, and adapt materials in an effort to tailor them to their students and respond to the constrained financial resources of their schools.

Even so, most surveyed teachers (76%) expressed confidence that their curricular resources were "mostly or "all" aligned to the Colorado state standards. Similarly, during the focus groups, most teachers reported that they were either engaged in aligning their curriculum to the standards or that their curriculum was already aligned due to prior efforts. For example Josette remarked, "We outfitted K-8 with Elevate Science. It is based on the NGSS, everything in it is NGSS. It takes you to the disciplinary core ideas, the cross-cutting ideas, all the way through." Marge shared,

> When we brought in that platform [Summit Learning] five years ago, Colorado was not on NGSS yet. But all of the information we were using, and all the resources we had access to, were NGSS-related. And so I actually had to re-adjust everything in those to align to Colorado state standards at the time. So I'm really pumped that we are finally fully adopting NGSS.

Those teachers who reported taking part in alignment efforts talked about a variety of tasks they were engaged in, including collaborating with the other science teachers in their schools, working across grade levels to determine how the curriculum could be vertically aligned and build on what students learned in earlier grades, mapping their curriculum onto the standards to determine what was missing, and looking for additional resources they could draw on to supplement their curriculum. A few teachers expressed little interest in NGSS-aligned curriculum and/or limited access to resources that would support efforts to become more standards-based. During a focus group, Deena acknowledged, "I know nothing about the new standards... I have really completely lost interest in them, to be honest... . We are just kind of good old-fashioned here."

Teachers' use of 3D assessments. The focus group teachers expressed variability in their familiarity with and use of 3D assessments. Teachers ranged from not knowing what the term "3D assessment" meant to shifting away from "traditional" multiple choice tests to actively seeking out or writing assessments that are more 3D in nature. The most common questions teachers had about 3D assessments were what they are, what good examples look like, and how to score them. Other questions included how to incorporate 3D assessments (and instruction) given a limited budget, how to make sure assessments (and instruction) work smoothly across grade levels, and how to ensure that developing and scoring assessments is not overly burdensome.

Among the teachers who were moving towards 3D assessment, there was general agreement that they should focus less on memorizing content and more on student demonstration of target "skills". Britte shared in a focus group that her school has been working to make their science assessments "somewhat 3D in terms of interacting with models and critical thinking, rather than just memorization." Kelly added, "Even if they are multiple choice, they're using their skills to answer questions, versus content knowledge."

Teachers who used project-based curricula generally expressed that their associated assessments appropriately gauged students' learning and "skills." Yet such assessments are often based on reduced sets of NGSS practices, which is not in keeping with the Framework's goals. For example, Sheila explained in a focus group, "Our district two years ago went to standards-based grading and we purchased Marzano's standards, which are based on NGSS." Other teachers indicated that they were incorporating project-oriented assignments (such as research projects and lab experiments) and were asking students to do more writing and/or speaking when they presented their findings in order to meet the SEPs in the Framework. Aside from teachers who used curricula that provided grading rubrics, it's not clear how such assignments were scored, or if scoring was 3D or 5D in nature.

Teachers who were not using the assessments provided by their curricular materials shared that they were actively searching for assessments or, in rare cases, writing their own. Teachers looked for assessment materials in books, internet resources, by attending conferences, from PL, and/or asking colleagues (typically in other districts). A number of teachers mentioned that they were actively seeking out, or would be interested in, PL opportunities related to assessment and that they were in need of more resources and examples/exemplars. A few teachers expressed that they were comfortable using more "traditional" assessment materials (a reference to content-based, multiple choice questions), at least some of the time. These teachers noted that they used traditional assessments for AP classes, to ensure students know how to take multiple choice exams, and to ease the burden of grading.

RQ4: What Are Rural Science Teachers' PL Experiences and Preferences?

Current professional learning opportunities for rural teachers. A large majority of surveyed teachers (82%) identified that some, a little, or none of their professional learning to date has been science-specific. Only 18% said most or all of their science PL has been focused on science. About 70% had some training in supporting emerging multilingual students and 94% of teachers had some training in using classroom technology. In focus groups, teachers reported that they did not have the opportunity to take part in science-specific PL as often as they want; they preferred content-focused workshops rather than those highlighting behavior issues, time management, or other topics that were not specifically connected to science learning. Similarly, although most survey respondents had received "some" or "a lot" of assessment support (n = 39), only 30 had received some or a lot of *science-specific* assessment support. Relatively few had PL that integrated assessment and the standards; 82% reported "none" or "a little" science assessment as it relates to the new standards, and 68% had "none" or "a little" training in using phenomena (in either curricula or assessment). Teachers also reported they felt excluded from PL opportunities that took place in the urban center of the state because they could not pay substitute teachers or miss multiple days of instruction for a 1-day workshop or conference (given that travel across mountainous states like Colorado can take a whole day). For the teachers in this sample, districts and schools provided the overwhelming majority (50%) of their PL.

Attitudes about professional learning. Virtually all surveyed teachers indicated they completely agree (73%) or agree (24%) that they "enjoy opportunities to develop my professional and classroom practices," and 71% agreed they derived valuable learning from school-based PL. Teachers shared that they would be interested in engaging in a variety of PL activities such as hands-on activities, examinations of student work (particularly from schools similar to their own), and discussions. Teachers expressed an interest in discussing wide-ranging topics such as equity, supporting students' interests, differentiated instruction to meet the needs of all their students, selecting and using phenomenon, and assessment practices. During the focus groups, teachers generally agreed that they wanted the PL to "offer a 3D experience," where the facilitator is knowledgeable and enthusiastic, and models effective instructional techniques such as using questions to drive their learning.

The focus group teachers also noted that both the facilitation and the focal content should be sensitive to their local, rural contexts. Sheila expressed concern that the presentation of certain curricular materials are not always appropriate for her students: "A lot of our kids have never been to a museum … So you have to really think about the examples that you use. And make sure that there's not a cultural bias because of where they live." Several teachers also explained they were especially hungry for collaboration with other teachers due to the small and isolated nature of their rural communities.

Discussion and Implications for Designing PL for Rural Science Teachers

RQ1: What Makes Rural Science Teaching Unique?

Teachers expressed their appreciation of the strong sense of community afforded by working in rural schools. The nature of their small schools means that these teachers often have the same students from year to year and are very familiar with the curriculum before and after their current year's science class, which enables coherence and alignment. Rural teachers in Colorado also reported finding enjoyment in the vast outdoor resources the state offers and shared creative ways they have connected those resources to their science instruction. At the same time, teachers reported challenges such as limited financial resources and access to instructional materials, geographic isolation from other science teachers and the larger scientific community, and navigating conservative beliefs that are sometimes in opposition to the scientific content they are teaching and the inclusive culture they are working to instill in their classrooms.

Implications: Equity starts with PL design. A professional learning design that centers equity for students must also ensure it is equitably including teachers. A number of teachers in this study were the "lone" science instructors in their school and had limited opportunities to collaborate with other science teachers. PL workshops for rural science teachers should offer a collaborative, supportive environment in which teachers learn about the conceptual shifts encouraged by the standards, are supported to work towards integrating more of the 5D practices, and develop curricular and/or assessment materials with role-alike colleagues. Rural educators consistently expressed a positive regard for the students and families in their communities; a promising next step is to intentionally construct opportunities for them to consider how to support their students' interest and identity alongside 3D learning.

RQ2: To What Degree Do Rural Teachers Report 5D Instruction?

The rural science teachers in this study conveyed that they were making broad efforts to align their instruction with 3D standards. However the teachers reported that they were, overall, not comfortable with common practices in 3D instruction such as conceptual modeling, engineering design, or considering alternative explanations and revising explanations over time. In terms of 5D science teaching, the participants reported moderately high student interest and engagement in their lessons, and they shared a large number of strategies that they have used to promote equity. Nevertheless the teachers' expressed priorities and practices did not reflect broadened attention to their students' interest and identity development. Their mean responses to questions about supporting interest and identity were lower, on average, than their responses to questions about using 3D instructional practices. It appears likely that the teachers prioritize other instructional methods over interest and identity-driven pedagogy.

Implications: Promote 5D Professional Learning

Interest and identity can be more systematically attended to with coherent professional learning that includes these constructs alongside the three dimensions of SEPs, CCCs, & DCIs. In general, the participating teachers appeared quite willing to structure their science classes to encompass 5D instruction, but they need support to consistently do so. Part of this support is likely to involve helping teachers develop the capacity to locate relevant phenomena their students are interested in and can identify with, that also helps them to make some connections between the science and their everyday lives (Penuel & Watkins, 2019; Stromholt & Bell, 2018). The fact that rural teachers reported having a wealth of information about their students and their families can serve as a rich starting place for 5D professional learning and instruction.

RQ3: What Curricular and Assessment Resources Do Rural Science Teachers Use?

Although most teachers in the study argued that their curriculum was aligned or somewhat aligned with the standards, very few of the named curricula that they reported using were deemed to be truly "aligned" via an external independent review, suggesting that teachers' views of "alignment" of their materials is not extending from research or consensus reports such as the National Research Council. A majority of teachers shared that they personally created and/or actively searched for instruction materials, suggesting that they had quite a bit of autonomy and could rely on their own judgement as to what "standards alignment" looks like. At the same time, this study did not assess teachers' competence in designing or critiquing instructional materials and there is likely much to be learned on this topic. Teachers generally expressed less familiarity with 3D assessment, described spending considerable time looking for assessment resources, and stated that they were interested in PL related to developing and using 3D assessments.

Implications: Teachers Need More Familiarity with the Standards

The mismatch between teachers' and researchers' perceptions of curricular alignment with the standards is critical information for leaders who support teachers working in rural contexts, and more attention should be paid to closing this gap. Rural science teachers would likely benefit from opportunities to gain more familiarity with the standards in order to become more accurate in determining the extent to which their classroom practices and resources are aligned. Teachers tended to express somewhat less confidence that their assessments mapped onto the standards, acknowledging that they lacked a strong enough understanding of what qualified as 3D assessment to judge whether their own assessments fit into that category. Topics that may be particularly important in increasing teachers' knowledge and moving their science instruction to be more in line with the standards include using phenomena to guide instruction, planning instruction related to the standards, and assessing students' 3D understanding related to the standards (Penuel et al., 2019; Penuel et al., 2020).

RQ4: What are Rural Science Teachers' PL Experiences and Preferences?

Teachers reported that much of the professional learning they have participated in is not science-specific. Additionally, science instruction and assessment aligned with the NGSS or other 3D standards was a topic that teachers reported receiving little support with. Clearly these rural teachers desired more and higher quality PL opportunities than they have access to. Furthermore, the teachers expressed a preference for personalized learning, with facilitators who were knowledgeable and sensitive to their local contexts and constraints, and with other science teachers to form a collaborative, science-focused learning community.

Implications: Make Professional Learning Science-Specific

Professional learning for rural science teachers should take advantage of promising new online designs for supporting teacher learning while accommodating their busy schedules and understanding their constraints (Durr et al., 2020). Resources should be mobilized at every level to better support teachers in designing and implementing 3D science that attends to students' interests and identities. One strategy that could prove effective is reaching out to leaders at universities, districts, and schools to provide PL opportunities for science teachers in particular and to consider making their programming available to virtual or asynchronous participants.

Limitations

This study is limited by its sample size and the depth to which we were able to gain a sense of teachers' contexts. We cannot discern the extent to which rural teachers in Colorado are similar to or different from teachers in other rural US teaching contexts. Although almost a third of the teachers who completed the survey were male, the teachers who elected to participate in the focus groups identified as female. The vast majority of teachers who completed the surveys and who took part in the focus groups identified as White/Caucasian, which generally matches the racial demographics of public school teachers in the US (de Brey et al., 2019) and we cannot make any assertions related to their positionalities. Future studies should seek to understand the nuanced needs of science teachers within different types of rural contexts, (e.g., large vs. small schools, farming communities vs. mountain communities, 6-12 buildings vs. 9-12 buildings) and in other states around the country. Additionally, this study was conducted during some of the most difficult months of the COVID-19 pandemic and teachers' time, physical health, and mental health were extremely taxed. Future studies may be better able to obtain a larger participation sample during a less stressful historical moment for teachers.

Conclusion

Enacting science pedagogies that encourage students to connect their everyday experiences and community interests with scientific knowledge and practices requires an understanding of what is currently taking place in rural science classrooms, the instructional priorities and practices of rural science teachers, and what resources are likely to promote or impede their growth. This study extends the research base of smaller-scale, ethnographic studies by providing additional evidence that rural education is replete with opportunities for including interest and identities in classroom instruction. While previous research has documented rural contexts as promising sites for interest- and identity-driven science interventions and designs (Eppley, 2017; Long & Avery, 2017; Zimmerman & Weible, 2017), this study looked more generally at patterns across rural teachers' self-reported practices, curricular and assessment materials, and professional learning. Findings from this study move the field a step further by addressing the larger question of "What PL supports might help teachers leverage interest and identity in assessment and materials design?", particularly within rural portions of a state in which many areas are geographically isolated and lack a strong infrastructure. Building on the assertion that there is "untapped potential" within rural areas (Harris & Hodges, 2018, p.10), this research offers direction for leaders seeking to build opportunities for rural youth through teacher development. In particular, science-specific, phenomenon-driven, online professional learning holds potential for meeting the expressed needs of rural science teachers, in support of their efforts to implement high-quality 5D instruction and assessment.

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