Research Article

Teaching science in rural elementary schools: Affordances and constraints in the age of NGSS

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Providing science instruction is an ongoing priority and challenge in elementary grades, especially in high-need rural schools. Nonetheless, few studies have investigated the factors that facilitate or limit teachers' science instruction in these settings, particularly since the introduction of the Next Generation Science Standards. In this study we investigated affordances and constraints to elementary science instruction in high-need rural schools. Data sources included semi-structured interviews and survey responses from 49 teachers from 30 different rural schools. Through a primarily qualitative analysis, we identified four teacher reported categories of affordances and four categories of constraints to teaching science. One category of affordances, access to a variety of outdoor science resources, and one category of constraints, high levels of isolation, were closely tied to the nature of rural schools. The other affordances and constraints are broadly recognized factors influencing science instruction. Implications for supporting rural teachers' science instruction are discussed.

Rural public schools in the United States serve approximately 20%, or more than 9.3 million students, in K-12 schools (Showalter, Hartman, Johnson, & Klein, 2019). These schools are located within complex socio-economic and socio-cultural milieu. One useful conception of the place of rural settings is captured in the idea of *urbanormativity* wherein urban and suburban settings are viewed as the norm, as they simultaneously depend on rural settings for resources and exploit rural settings for those resources (Thomas & Fulkerson, 2017). *Urbanormativity* helps contextualize the marginalized nature of rural schools within the larger educational system. Rural schools are not heterogeneous, however, and have distinct characteristics based on their location, population, and histories (Hunt-Barron, Tracy, Howell, & Kaminski, 2015).

Rural schools and districts tend to be smaller in terms of the number of students served, but are also in communities that are sparsely populated, that are spread over wide areas, and that offer parents limited choices about where their students can attend school (Avery, 2013). Rural schools tend to be located in remote areas and experience volatility in student enrollment due to economic shifts; possibly leading to either declining or increasing enrollment (Avery, 2013). Rural settings also provide a number of unique affordances for students, and include the local funds of knowledge present in rural communities broadly, as well as the backgrounds and daily experiences of rural school-aged children (Avery & Kassam, 2011; Avery, 2013; Kassam & Avery, 2013). An example of this historically and culturally developed knowledge is students' experiences fishing, hunting, and interacting with Indigenous knowledge. It is within this dynamic system that rural schools and districts are charged with preparing students to meaningfully engage with science in ways that help them make sense of the world (NGSS Lead States, 2013).

The Next Generation Science Standards (NGSS), introduced in 2013, call for significant shifts in the way science is taught (Bybee, 2014). Central to these shifts is a transition from rote memorization of canonical facts to students being able to explore and make sense of real-world phenomena around them and connect these phenomena to science concepts (Stage, Asturias, Cheuk, Daro, & Hampton, 2013). The NGSS calls for students to explore ideas, discuss and develop arguments from evidence, and to defend conclusions based on evidence (NGSS Lead States, 2013). Beyond the standards themselves, teachers' perceptions of their students and their own engagement with teaching science exert influences on how the NGSS is enacted (Bybee, 2014). Indeed, teachers play a central role in the learning that takes place in a classroom (Ball & Forzani, 2009), including the science learning opportunities afforded to students.

In the elementary grades, science instruction is critical for children's development of science concepts and ideas (Lee & Luykx, 2007). Nonetheless, science instruction in the elementary grades is challenging for a number of reasons. Elementary school teachers have to teach multiple subjects, including language arts, mathematics, and social studies, as well as multiple components of science, including physical science, life science, and earth science (Davis & Smithey, 2009). Elementary teachers typically have limited subject matter backgrounds in science, often being more knowledgeable in subjects such as language arts (Epstein & Miller, 2011). Furthermore, elementary school teachers often feel uncomfortable teaching science (Banilower et al., 2013). In rural settings, these challenges are further complicated by limited resources and professional and geographical isolation from other teachers (Avery, 2013; Barley & Beesley, 2007; Farmer, 2009).

Although the instructional challenges to teaching science in rural settings persist, the need to provide students with meaningful learning experiences remains a national priority (NGSS Lead States, 2013). A great deal of attention has been given to the persistent STEM learning opportunities gap (Darling-Hammond, 2010; Flores, 2007). However, whereas greater attention has been given to the specific contexts of urban schools, less attention has been paid to the unique contexts of rural schools and the implication of those contexts on teaching and learning (Biddle & Azano, 2016). Even less attention has been given to science instruction in rural settings (Avery, 2013).

Given the central role of teachers to instruction and student learning, it is important to identify the constraints and affordances that shape rural elementary teachers' opportunities and decisions to teach science. Two questions guide our inquiry:

1. What instructional affordances do rural elementary teachers identify as influential in teaching science?
2. What instructional constraints do rural elementary teachers identify as affecting their science instruction?

Theoretical Framework

We take a situative perspective to examine the affordances and constraints on rural elementary science teachers' instruction (Greeno, 1998). A situative perspective is a useful lens as it views learning and teaching as part of an activity system, where teachers and students interact as part of classrooms in schools within larger communities. This approach facilitates a system-level perspective rather than a focus on teachers as sole actors in teaching. Furthermore, this approach allows us to attend to the complexities of teaching in rural settings, taking place within larger communities (Burton, Brown, & Johnson, 2013). Indeed, instruction in rural classrooms is influenced by numerous factors within and outside of the classroom. These factors range from the larger policy level, to school-specific factors, to available tools and resources within the classroom.

We draw on a resource framework to examine instructional affordances and constraints. Instructional resources are central to teaching, range from intellectual to physical, and can include frameworks for planning instruction as well as tangible tools and materials used as part of teaching (Lampert, Boerst, & Graziani, 2011; Stroupe, 2016). In this study, we view instructional affordances as access to resources, and instructional constraints as a lack of resources. In the context of science instruction, affordances can include lab materials, curriculum, a community of peers with whom teachers can develop instructional practices, and time. The availability of instructional resources underpins any desired shift in instructional practices such as those proposed by the NGSS. Indeed, a lack of instructional resources has been identified as a central constraint for achieving the type of instruction advocated by policymakers and researchers (Darling-Hammond, 2010; Hellsten, Mcintyre, & Prytula, 2011).

Affordances and Constraints in Rural Instruction

Two major categories of instructional affordances emerge from the literature on rural education: professional development, and administrative and community support. The availability of professional development to support teacher learning encompasses a wide range of activities and interactions. Availability of professional development includes access to professional development from experts and those outside of a school, as well as time and opportunities to collaborate with other teachers at the school site (Glover et al., 2016; Goodpaster, Adedokun, & Weaver, 2012). Professional development is a way to break down teacher isolation and to build networks with other teachers (Hellsten et al., 2011). Supportive principals also serve as an important resource for rural teachers (Anderson, 2008). Principal support of rural teachers manifests itself in a number of ways, including developing a constructive school culture as well as facilitating teacher access to professional development (Avery, 2013).

The findings of these rural-focused studies align with the larger field on improving instruction broadly and science instruction specifically, where professional development as well as supportive school leadership and culture are critical to teacher learning (Heck & Hallinger, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Nonetheless, there are few studies on rural professional development and what teachers gain from it, especially in the area of science, and calls have been made to explore this area further (Glover et al., 2016; Goodpaster, Adedokun, & Weaver, 2012).

Given the complexities of teaching, it is not surprising that challenges related to professional development are reported as instructional constraints in rural settings. Challenges explicitly connected to professional development include a lack of mentoring and a lack of university-connected professional development resources (Goodpaster et al., 2012). A lack of materials, such as lab consumables and even paper, as well as a lack of human resources, such as mentors, are also reported (Hellsten et al., 2011). Additionally, rural teachers have reported a lack of knowledge as an instructional constraint. Teachers lack knowledge related to instructional content, and, for those who have relocated from other communities, knowledge of rural communities and schools (Burton et al., 2013; Hellsten et al., 2011).

Resources and Science Instruction

Science, perhaps more than any other subject, calls for a wide range of materials and activities for students to experience meaningful learning. Consequently, a lack of materials has been a central concern in schools in underserved communities (Darling-Hammond, 2010; Johnson, 2006). This lack of resources encompasses physical materials, such as consumables and curricula, as well as human resources, which may either afford teachers opportunities to engage with peers and learn, or constrain their learning opportunities (Johnson, 2006; Markow, Macia, & Lee, 2013). Teacher isolation poses a significant constraint on teachers' ability to develop and improve science instruction (Rodriguez, 2015; Tobin, 2000). Most of these studies have taken place in underserved urban settings, raising the question of how these instructional challenges manifest in rural schools and what affordances support teachers' science instruction.

Method

Study Context and Background

This qualitative study is part of a larger longitudinal research project examining the extent to which modest supports for elementary teachers influence the sustainability of science professional development outcomes over time. The study took place in 19 districts and 30 schools in rural communities in California. Although California has the 14th largest population of rural students in the country (over 220,000), rural students only represent 3.5% of the state's total student population. The majority of rural districts are considered small (68.6%), accounting for 11.5% of all schools in California (Showalter et. al., 2019). The districts in our study varied widely with school populations ranging from 158 students to 918. Demographics of the participating districts and their students are detailed below (see Table 1).

The current study includes 49 K-6 school teachers, with 44 teaching a single grade and five teaching combination-grade classes (see Table 2). All participating teachers completed a prior science-focused professional development program and volunteered to participate in the current study. Given the teachers' prior and current commitment to improving their science instruction, we characterize them as highly engaged and interested in implementing NGSS-aligned science instruction at the elementary level. The teachers came from 30 schools located in 19 districts. In most cases, teachers were either the only participant or one of two participants from a given school; there were three schools from which three teachers participated, and one school from which five teachers participated. The participating teachers were interviewed and completed a survey in the spring of 2017 prior to their participation in the research project.

Table 1
Participating Districts and School Demographics

Districts and Schools		District Student Race/Ethnicity Breakdown								District Student Population	% of Families with Income Below the Poverty Level	Locale Code Description
District ID	# of Schools	*African Am.*	*Am. Indian or Alaska Native*	*Asian*	*Filipino*	*Hispanic or Latino*	*Pacific Islander*	*White*	*Two or more races*			
1	3	1%	3%	1%	1%	21%	0%	67%	6%	3,962	Not available	Town, distant
2	1	5%	0%	20%	5%	45%	1%	18%	6%	872	28.10%	Rural, fringe
3	1	0%	2%	0%	1%	20%	1%	68%	8%	158	10.50%	Rural, fringe
4	1	1%	3%	1%	1%	15%	0%	73%	0%	487	32.90%	Rural, fringe
5	2	1%	0%	1%	0%	48%	0%	47%	2%	2,992	15.90%	Town, fringe
6	1	2%	1%	3%	0%	26%	0%	64%	3%	1,030	3.20%	Town, fringe
7	2	1%	4%	1%	0%	26%	0%	60%	3%	384	9.10%	Town, distant
8	4	1%	0%	1%	4%	43%	0%	48%	3%	3,872	14.70%	Town, distant
9	3	1%	1%	2%	1%	62%	0%	32%	2%	2,318	13.60%	Rural, fringe
10	2	2%	0%	4%	0%	69%	1%	16%	4%	15,569	38.10%	City, midsize
11	1	2%	0%	0%	1%	85%	2%	9%	3%	201	Not available	Rural, distant
12	1	2%	0%	1%	1%	76%	0%	17%	3%	3,225	20.20%	Town, distant
13	1	1%	2%	1%	1%	14%	0%	75%	7%	4,154	23.10%	Town, fringe
14	1	2%	0%	5%	2%	35%	0%	47%	9%	4,628	14.60%	Suburb, small
15	1	3%	0%	4%	1%	60%	1%	26%	3%	3,310	18.20%	Suburb, large
16	1	0%	2%	3%	1%	15%	0%	75%	4%	742	37%	Town, distant
17	1	0%	1%	1%	0%	17%	0%	71%	6%	584	13.80%	Rural, remote
18	1	4%	1%	15%	1%	68%	0%	9%	3%	2,871	46.70%	City, small

Table 2
Teacher distribution by grade level

Grade	K	1	2	3	4	4-5	5	5-6	6
Number of teachers	3	4	3	11	10	3	10	2	3

Data

Two data sources are used in this study: an online needs assessment survey and a semi-structured teacher interview lasting approximately 45 minutes. The survey was designed to provide a broad overview of the types of affordances and constraints that participating teachers experienced in their efforts to teach NGSS-aligned science (N=48). The interview was designed to provide additional context and details about the nature of affordances and challenges encountered by these teachers in different classrooms and schools (N=49). The survey included Likert-type scale questions as well as open-ended questions. The Likert-type scale questions asked teachers about the barriers and supports they had at their school sites to teach science and the types of support they most needed. Additional open-ended questions asked teachers to describe the aspects of the NGSS with which they needed the most help.

In the interview, teachers responded first to questions about their teaching context, which offered a sense of the teachers' working conditions, prior science teaching experiences, and backgrounds. Teachers were then asked questions about the challenges that they encountered in teaching science at their schools, and more specifically, teaching science in ways aligned with the NGSS. Interviewers also asked teachers about their instructional needs and sources of instructional resources. Furthermore, teachers were asked what affordances they had available to teach science in their classrooms, schools, districts, and counties. All interviews were audio recorded and transcribed. All transcripts were then uploaded to qualitative analysis software (MaxQDA).

Interview transcripts were initially descriptive-coded by idea units. These coded segments were distinct ideas based on the teachers' answers to questions, where a single answer consisted of one or more idea units. For example, teachers were asked, "Are there any specific barriers that make it challenging for you to teach science?" in response to this question, if a teacher mentioned a lack of knowledge of the NGSS and a lack of time, this response was broken into two idea units, one relating to knowledge and one to time. A total of 3121 segments were generated across the 49 interviews. From the 3121 initially-coded segments, 166 were identified as containing affordances and 336 were identified as containing constraints. These segments then became the basis for the detailed analysis of affordances and constraints described below. For purposes of reliability, one researcher initially identified and coded each segment, and another researcher reviewed the generated code. Any discrepancies between the two were noted, discussed, and resolved.

Data Analysis

The goal of our analysis was to provide both a broad overview of supports and constraints, as well as finer-grained detail about the affordances and constraints teachers reported. We wanted to move beyond reporting frequencies of categories and explicate how affordances and constraints manifest in teachers' attempts to teach science. Survey data were primarily used for the broad overview, and interview data were primarily used for the finer-grained analysis. We took a bottom up approach to our data analysis, allowing themes to emerge from the data as it was analyzed. We connected our themes to existing literature on science teaching and teaching in rural settings (e.g., Goodpaster et al., 2012). We build on existing themes with our focus on the introduction of the NGSS standards. Greater detail of the analytic approach is provided below.

Survey data. From the needs and supports survey, we focused on two areas. We analyzed responses to open-ended questions about what teachers most needed to teach science generally and to teach science under NGSS more specifically. We were interested in both of these questions as it was expected that the change in standards to the NGSS would create needs distinct from just teaching science. Responses to the needs question were initially descriptively coded and then thematically coded (Saldana, 2016) based on science instructional needs identified in the research literature as well as emergent themes from the data.

Interview data. The purpose of the analysis of interview data was to provide details and context as well as major themes of affordances and constraints that impact rural elementary teachers' science instruction. The 166 identified affordance segments and 336 constraints segments were initially coded descriptively by one researcher. For example, the following segment was identified as a challenge: "We are struggling with… moving into the Next Generation Science Standards without the information we NEED to do it." This segment was descriptively coded as the teacher needing additional information about NGSS. Descriptively coded segments were then organized by themes. For example, the segment above was coded as a thematic challenge of lack of NGSS knowledge. A second researcher coded the segments based on the thematic codes that were generated. Any disagreements in the coding were reconciled through subsequent meetings. Once all the segments were coded, broader categories of affordances and constraints were generated based on the existing literature as well as from emergent themes from the data. With the example above, the challenge was broadly coded under the category of lack of knowledge, which emerged from the data. In some cases, the categories aligned with existing literature, for example a lack of access to PD. Categories were further organized as general or rural-specific.

Findings

Before identifying affordances and constraints, we wanted to get a sense of what teachers reported they needed in order to teach NGSS-aligned science in rural settings. This analysis provided us with context for what was being facilitated by affordances or limited by constraints. Teachers identified four main needs which they sought to teach NGSS-aligned science (see Figure 1). First, 40% of teachers reported that they needed curriculum to teach NGSS-aligned science. Second, 21% of teachers reported feeling constrained by a lack of understanding of the standards and what they meant instructionally. Third, 17% of teachers reported that they needed materials and resources, and, fourth, 17% of teachers identified a need to improve their general pedagogy in order to implement NGSS-aligned instruction.

On the whole, teachers reported that most rural schools had been focusing on implementation of the Common Core State Standards (CCSS) and had done little to support implementation of the NGSS. As one teacher reported, "When looking at NGSS I get very overwhelmed. I'm not sure where to start or what they want me to cover. The old standards were more like a list of things to cover. I feel NGSS is more open to interpretation and I'm not sure where to start." The need for curriculum was driven both by

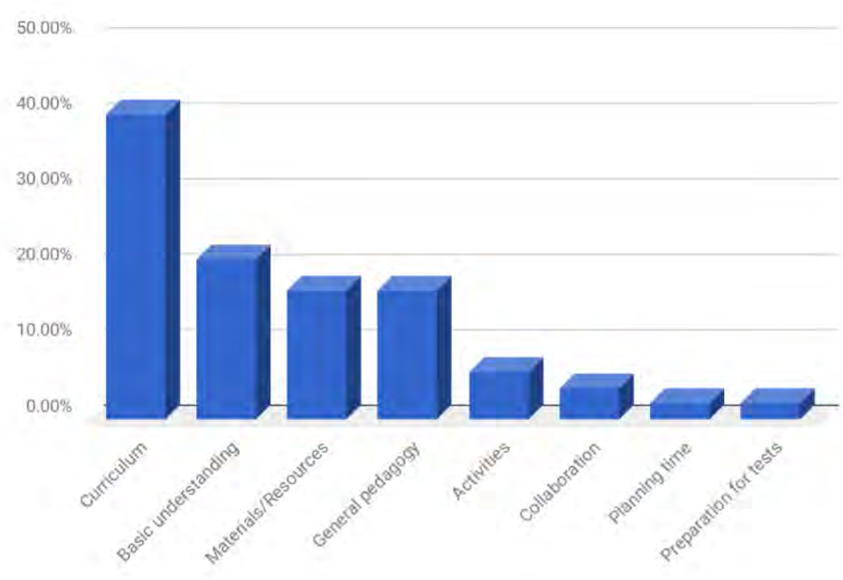

Figure 1 Resources teachers reported as most needed to support standards-aligned science instruction

this change in the overall instructional approach called for by the NGSS as pointed out by the teacher above, as well as the changes in concepts covered in certain grade levels. Some of the teachers in the study had recently changed grades and were challenged by this change in subjects covered. Furthermore, in California, the third- and fifth-grade content for NGSS are reversed when compared to the prior state science standards, meaning that for those two grades, teachers would have to implement an entirely different curriculum.

We found that 48 of the 49 teachers in this study reported at least one affordance, and all 49 teachers reported at least one constraint to teaching science in a rural setting. This finding provided us with initial considerations for the instructional complexities which frame teachers' ability to teach NGSS-aligned science in rural schools. In the following sections, we present the affordances reported by the rural teachers followed by the constraints. We then examine the relationship between affordances and constraints. We note that although there are some broad-based affordances that were identified across many rural settings, there were also highly localized affordances and constraints.

Affordances

Four major categories of affordances emerged from the survey and interview data. One category in particular, access to relevant outdoor science activities, highlighted the connection between rural schools and local agencies and organizations such as the Forest Service. The three other categories were: access to professional development, a supportive principal or district/county science specialist, and online resources. In the surveys and interviews, teachers identified administrator support as a key affordance; the remaining categories emerged from teachers' responses in the interviews. Although we present these affordances as four distinct categories, there was some overlap between them. For example, principals facilitating access to professional development spans both the professional development and administrator support categories.

Access to outdoor science-related activities. The easy access to lakes, rivers, and other bodies of water near some of the schools was a rich resource for some of the teachers. As one teacher reported, "We had a ton of rain and mudslides this year, so tying it [instruction] to real life things. We can even walk down to the park and look at their tower of water and see changes to the river. We have a river right down the street. So we can walk down there." These resources also tied in with local histories and cultures, often connected to farming and fishing. A number of teachers reported formal partnerships or programs with local agencies that afforded their students opportunities to experience science in authentic ways. Often these programs related to water and conservation.

Beyond seeing and engaging with nature, teachers described programs in which they visited local rivers and creeks, collected and analyzed data, and reported their findings. These activities allowed students to engage in scientific practices aligned with NGSS and in ways that scientists carry out investigations. For example, one teacher shared that "[someone] from the Forest Service was just here and talked about water quality. Water quality experiences, just taking local water and looking for…it was called a snapshot day so they take the data that our kids collected and use it for their data on the health of our water systems in the area." Thus, these programs facilitated the connection between real-world, relevant, scientific phenomena in close proximity to the students, which is advocated by the NGSS.

Programs with organizations such as the Forest Service provided a bridge for students and teachers to access curricula and experiences that they may not have had access to in their own classrooms, or that may not have been aligned with the principles of the NGSS. It is of note that schools located closer to resources from federal and state agencies, such as national or state forests, or universities, had greater access to these types of resources. The sizes of schools or districts did not seem to have an impact on access to these resources. We found teachers, from single school districts serving 400 students and teachers from districts serving over 3000 students connecting with and using these outdoor resources. One teacher who sought such resources pointed out that, "[The] Forest Service Institute is coming up with three or four different things you can go to and none of them are around here, they are all four or five hours away," making them inaccessible to the teacher and their students. There was also a level of instability with these types of resources, as they sometimes depended on long-standing programs, and in other instances depended on programs that may have run for a few years and then were discontinued.

Professional development. Professional development was the broadest affordance category and captured a number of features and types of professional development that supported teachers' science instruction. Since small rural school districts tend to have limited capacity for professional development (Harmon & Smith, 2012), the rural teachers in this study highly valued professional development opportunities. Two categories of external or off-site professional development emerged, one focusing on knowledge of the NGSS, and the other more broadly addressing instructional tools and strategies that they might apply to science instruction. Tools and strategies that teachers described learning in professional development included guided language acquisition design (GLAD), notebooking, the use of science kits, and developing outdoor activities. Many of these strategies and tools had been the substance of professional development programs that teachers completed as a precursor to this study. These professional development programs also provided teachers with kits, curricula, and materials to facilitate science instruction. We note that, although these strategies and tools were not explicitly framed as part of NGSS instruction, they were typically in alignment with the new standards.

Two additional benefits from the professional development emerged: increased teacher confidence and opportunities for teacher collaboration. Teachers reported that the professional development helped them with their confidence in teaching science. As one teacher commented, "Listening to the different presentations and the different experiments, it just gave me…the comfort level and assurance that 'I am good here, I can do this.'" These professional development sessions worked to break down isolation, as another teacher noted (all locations are pseudonyms):

> Being rural, we are not close to each other, so my school is in Jackson and there's one in Plymouth which is a half hour away. Pine Grove is about 20 minutes down the highway. Pioneer is further out. So we are kind of spread all over the place, so we didn't really know ourselves very well. [The professional development program] was the first place where I really got into working with other teachers and being able to talk to them about problems I was having and getting help; that was really eye-opening. That was a lot of the strategy we used; if nothing else, being together and then incorporating more of the trying to work with groups and stuff like that.

In addition to the substance of learning facilitated by the professional development, through these collaborations, teachers were able to get additional help from their peers with challenges they encountered in their own classrooms.

A few teachers had opportunities to collaborate at their school sites through professional learning communities (PLCs). As one teacher pointed out,

> We have some time set aside. We have early dismissal on Thursdays so we get together to do PLC time and that's one of the things that we do during our field study, PLC time and stuff. To work out some activities…so I plan a lesson and then we'll do that same lesson over two weeks.

This type of collaboration appeared to occur more often under specific conditions: in larger schools where there was greater potential for collaboration (typically where there were multiple teachers at each grade level); when specific time was allocated for this type of collaboration; and when teachers had a common vision or program to drive their collaboration.

Locally, teachers had the opportunity to engage in professional development related to the environment around them. For example, one group of teachers engaged in a joint professional development with the Forest Service where students learned about salmon migration and visited a local river and collected data. These professional development opportunities were more closely tied to location than size of school, or rural school designation. In addition to the wide range of professional development in which the teachers engaged, access to professional development was facilitated through a number of sources. These sources in some cases informed them of professional development opportunities and in some cases encouraged and facilitated their attendance. Teachers cited their principals, the district, the county, local organizations such as the Forest Service, institutions of higher education, and other teachers at their own school site as facilitating access to professional development.

Supportive principal or district/county science specialist. Principals primarily supported teachers indirectly in their instruction of science. Indeed, only two of the participating teachers reported that their principal had a science background and could potentially support them directly with content and NGSS-aligned instruction. Principals primarily provided time and materials for teachers. Time was provided onsite for teachers to plan and to attend professional development. As one teacher pointed out, “We talked about this and I moaned and moaned, ‘Come on, we have to do this.’ My principal had extra Title One money and she is offering a training for K-5 teachers with two days in the summer.” Materials provided by principals included various resources such as curricula, kits, and access to online resources. There did not appear to be a connection between school size or locale and principal support. Although few teachers explicitly pointed to a supportive principal, they came from a wide range of schools and districts. Teachers reported different types of systems and relationships with administrators regarding procurement of materials. As described above, in some cases teachers had to press principals for resources; in other cases, routines had been established for teachers to get resources; and in rare cases, principals were proactive in providing resources. As one teacher reported, “We have a science lab coming up next week and they asked us if we needed any supplies. They would provide money for that, which is good. I guess that would show that the principal is more actively engaged in science. It’s a routine now.”

District and county-based experts emerged as an important resource for the teachers. In some cases, these individuals were recognized as experts but their role was informal. As one teacher explained, “He is the go-to person for science in our district, and it’s not a formal role that he plays at all. But everyone knows if there is anything we have a question about in science at the elementary level, he’s the one that’s going to know the answers.” Thus, networks of support were developed around a single science specialist. The science specialists themselves also developed a peer network, building a collaborative community of specialists. This network was formed in response to teachers’ limited access to experts and resources beyond their peer community:

> I find I get more support from other science specialists at different districts throughout our county. We don’t have a science specialist at Jamestown, so I don’t really talk science with my peers because I’ve been teaching longer than them, so they are the ones usually asking me for information. But when I need help, I ask my neighbor who happens to be a science specialist at the same grade level in a different district. That is really where I get my support.

Through these networks, science specialists were able to continue to develop their own expertise and support other teachers in their districts. These specialists served a wide range of teachers, primarily from larger districts, but also, as noted above, teachers from smaller schools who did not have local supports.

Online resources. Teachers identified several online resources as sources of instructional materials. For many of the teachers, online resources offered ways of overcoming limited local resources and the isolation they experienced in rural schools, especially in the area of limited or outdated curriculum (Hellsten, Mcintyre, & Prytula, 2011). One teacher shared the importance of online resources

> I pull something off the internet or wherever I can...to get engaging lessons that get to those standards I know they are going to be tested on. Now it is all very confusing. Our district has not given us [curriculum] for NGSS yet and they are not assessing that yet but they are not assessing the old standards either.

In other cases, students engaged with online resources directly, because teachers were able to get more current and updated content that their textbooks and curricula did not have.

Interestingly, few teachers reported using the same resource, which suggested that they were primarily finding and accessing these sites on their own. Sites included well-known lesson plan resource repositories such as teacherspayteachers.com and betterlesson.com. In some cases, teachers used online resources for needs beyond curricula, such as videos. As one teacher pointed out, “I use Bill Nye for videos and I use certain internet resources to support what I am trying to teach.” This example reflects that some teachers used multiple online sites. Finally, some teachers used image repositories such as Pinterest to gather images.

Beyond the different types of instructional affordances, we saw that the types of supports teachers had access to varied markedly. Whereas some teachers had a broad base of support from administrators who facilitated professional development, or had access to local science teacher experts, others had to be self-reliant and find resources online. Affordances that were more proximal to teachers appeared to be more contextualized to their particular needs and settings. For example, whereas the outdoor activities connected teachers and students to their environments, lessons or videos obtained online were typically more generic or decontextualized.

Constraints

Four major categories of constraints to NGSS-aligned science instruction emerged from teacher responses. One category appeared to be most acute in these rural settings: isolation and lack of human support. The three other categories encompassed materials and curricula, time, and a combination of lack of knowledge and discomfort with science instruction. In the following sections, we describe and contextualize what each category represented. As with the affordances, although we present four categories, we do not view them as entirely discrete. Indeed, there were numerous intersections and overlaps between these categories.

Isolation and lack of human support. Teachers reported being isolated across multiple dimensions, including within their schools and within the district or county. Teachers reported a lack of opportunities to engage in professional development or professional communities that might reduce their isolation. Both of these findings reflect broader rural school challenges of limited capacity to support professional development locally, as well as large distances that need to be traveled between schools (Avery, 2013; Harmon & Smith, 2012). Additionally, teachers identified leadership turnover at the school and district levels as creating challenges and contributing to a lack of continuity. Teacher turnover also presented challenges in building community, expertise, and collaboration. Finally, some teachers reported that their districts were overwhelmed by the transition to new standards and could provide little to no support. It is of note that these challenges were not apparent from our survey data, but emerged from the teacher interviews. Additionally, the broad challenges with NGSS adoption cut across schools and districts and appeared to be a large and persistent challenge.

Most of the teachers in the study were the only ones teaching a given grade at their school. This isolation within their own site significantly limited their ability to collaborate, design instruction, or reflect with peers. As one teacher stated, “I think, just hoping I am getting all the curriculum covered and being all by myself, I don’t have another kindergarten-level teacher to talk with and plan with.” This challenge highlights the limited affordance of partnership and grade-level collaboration that is only available to the few teachers in larger rural schools. Other teachers expressed frustration at the lack of opportunities to work with other teachers: “I am starting to feel cut off from my fellow teachers in general. I don’t even go eat lunch in the lunchroom anymore.”

The lack of professional development opportunities that some teachers experienced contributed to isolation. As one teacher shared, “Things just closed up and there was no professional development. There’s never any money for anything. I have to pay for everything. If I do anything, I have to pay for it myself.” The majority of teachers reported that they had not had any science professional development in the prior year. Some shared that they had not had any science-focused professional development in multiple years. This was especially true concerning the NGSS, to which teachers had very limited exposure. The challenges with professional development were at times attributed to lack of district support:

> I feel like our district is really far behind on transitioning to these new standards and they really haven’t been very supportive in getting us transitioned. They haven’t given us any professional development; they don’t seem to care that we are really close to being tested. I feel like they are so worried about other things that they kind of dropped the ball on the science part of it.

Here we also see a potential consequence of the focus on language arts and math in elementary schools. As one teacher pointed out, “I think they [administrators] try to be [supportive of science instruction] and I think if you asked they might be, but I think they are just so concerned about the test scores in reading and math, that is where they are putting all their time and effort.” Teachers did not necessarily blame the district. Some of them empathized with the various priorities that had to be balanced, but a large proportion of teachers viewed the district as unsupportive.

Finally, teachers cited leadership changes at the school and district levels as destabilizing and leading to confusion, challenges, and increased isolation. One teacher informed us that, “We’ve had turnover and we have an interim superintendent and then we have had major issues with our curriculum director and we just this year got a new curriculum director who kind of inherited a mess, so the last thing she wanted to hear about was us.” Other teachers shared similar stories where changes in leadership resulted in shifting priorities, created confusion and isolation as new administrators settled in, and, in some cases, left before they could even settle in. Similar to the other constraints, isolation and lack of human support limited what teachers who wanted to engage in NGSS-aligned teaching could do to improve their instruction.

Material and curricular needs. In their survey responses, over half of the teachers identified some aspect of materials and curricular challenges as a constraint to science instruction. Material challenges primarily related to consumables for experiments and hands-on activities, as well as curriculum to drive instruction. Part of this constraint was driven by a focus on language arts and mathematics related to the emphasis on implementation of the Common Core State Standards. Specifically, curricular adoptions were taking place for language arts and mathematic ahead of science, and the rollout of these adoptions pushed back the introduction of NGSS-aligned science materials. One teacher, for example, explained: "There is a commitment at some level [to NGSS]. I think it is important. I think with everything we have to do in terms of new math curriculum, new language arts curriculum and state testing, science is at the back of the list, understandably." This perspective reflects what other teachers reported as well. Although they were committed to science instruction, the teachers understood that it was not a high priority. These findings are consistent with prior studies that reflect broad financial constraints experienced in rural settings (Harmon & Smith, 2012).

In terms of lab materials, although many of the teachers wanted to conduct experiments and hands-on activities with their students, some had very limited access to the tools and consumables required. Indeed, a number of teachers had to change their instructional approach due to lack of materials. This teacher's comment exemplifies the issue:

> Today I was trying to find a 100 ml graduated cylinder and we have two on the campus. So this is going to become a demonstration...Now that this is not an experiment, it is a demonstration in front of the class and I will ask a whole bunch of questions and ask them to talk about it. I would much rather have them doing this at their own tables, but materials dictated otherwise.

Here we see how students were unable to experience richer instruction due to a lack of basic lab materials. The example above also illustrates how material constraints undermine hands-on science instruction even when there is a will and desire to teach science in ways that are more engaging to students.

In some cases, teachers reported buying materials and consumables themselves, often citing the economic hardship this created for them. Some teachers organized fundraisers to provide students with resources: "We have to do a lot of fundraising…in fact on Saturday, I am doing a fundraiser." In other cases, even when materials were available, teachers reported that organizing them and setting them up was too time consuming and challenging, which kept teachers from engaging students in experiments and hands-on activities.

When it came to curriculum, the dearth of NGSS-aligned materials dominated teacher responses. The few exceptions to this problem were found in two districts that were large enough to create curriculum development teams of teachers at the district level (serving approximately 4000 students each). Nonetheless, across most districts, teachers reported receiving the NGSS standards but little to nothing more. Some teachers expressed frustration at only having access to outdated books and curricula:

> I think lack of good lessons. You look at a lesson and they are supposed to read a chapter and I am like, "Really?" You kind of have to follow the curriculum of your school site, so that makes it a little frustrating. It's like I am supposed to follow this book, and this book is not really good. It is boring to have to read this chapter. That's not science, just reading, period, and that's it. I think that would be the negative for me.

Despite these types of challenges, some teachers attempted to change or modify existing curriculum to align with the NGSS, but those who did often cited challenges with time as described below.

Time constraints. Lack of time has often been cited as an instructional challenge by teachers (Heller, et al., 2012; Morton & Harmon, 2011). As one of our participants pointed out, "I do so much stuff. Could you just expand the day for us? That would be awesome. Couldn't we just have a 30-hour day every once in a while?" Her comment highlights the constant challenge for teachers to accomplish everything they need to do on a daily basis. Our finer-grained analysis of interviews found that there were a number of factors and components that contributed to this challenge. Time for instruction, time for planning, and the intersection of time for planning and instruction, were identified as challenges. The availability of planning time was the category in which teachers reported being least supported at their school sites.

Time for instruction emerged as a challenge linked with the implementation and emphasis on the Common Core State Standards and related student testing. In survey responses, teachers reported having the flexibility to teach science somewhere between "somewhat available" to "moderately available" (average 3.31 on a 5-point scale). Nonetheless, many teachers indicated that they had to dedicate the majority of instructional time, often the first half of the day, to language arts and math, and then had the portion of the day after lunch to balance science, social science, and other subjects. As one teacher said, "With all the time they want us doing math and language arts, it is very hard to feel like we are doing enough science." Indeed, some teachers reported that they were only able to teach science two days a week.

Beyond instructional time, planning time emerged as a challenge in science instruction. Planning was connected to activities in science that required preparation, such as setting up lab activities. Additionally, lesson and instructional planning for the transition to the NGSS was identified as a challenge. Furthermore, teachers' lives and demands from other subjects limited their planning opportunities. One teacher described the challenge this way:

> I have three of my own children and I have a life after school…There is a lot of planning that goes into this revamping [NGSS-aligned instruction]. It's a lot of work. Even though I know I need to tweak this, I need to change that, it doesn't happen, then I think I'm going to do this over the summer and I get some of it done. It's baby steps. It's slow going and it's time and it's not necessarily time in the classroom, it's time to sit down and think about it.

In this example we see the limitations and constraints experienced by teachers as they attempt to develop curriculum and activities for their students with limited time, and the challenge of balancing competing priorities in and outside of school.

Time constraints were raised in more challenging situations, where curricular materials were not available, and teachers had to create their own. As one teacher stated,

> I think I am going someplace that doesn't have curriculum written for it [the NGSS] already, so it is the time I need to sit down and create the unit which, you know, when you get curriculum anyway, you need to sit down with it and see what works and what doesn't work. That's my thing I think, making sure that I am getting the needs met for my children. As the first year of going through that it's like, "I don't have time for this" or, "This took much longer than I thought."

In these examples, we see how a lack of NGSS-aligned curriculum or general lack of curriculum creates time pressure for teachers. These examples also present some potential explanations as to why teachers continue to use outdated curricula with which they are familiar. In all cases above we see that even when teachers wanted to engage their students in science learning, they were constrained by time.

Discomfort teaching science and lack of content knowledge. Elementary school teachers rarely have undergraduate degrees in science and often feel unprepared to teach science (Lee & Luykx, 2007). Indeed, in our study, teachers shared some of these sentiments: "Out of all the subjects, it [science] is probably my least favorite...Given a choice, I would teach social studies and, you know, reading all day long because it is easier for me." In addition to teachers' general discomfort with teaching science, we found two broad categories of knowledge that challenged teachers' science instruction. First, there was a general lack of pedagogical content knowledge and science content knowledge. Second, with the introduction of the NGSS, teachers were faced with having to teach and potentially create curriculum for a set of standards about which they knew little. In survey responses, 21% of teachers reported that they needed to develop at least a basic understanding of the NGSS, and 17% reported that they needed support in instructional pedagogy in order to teach science.

Most teachers reported limited implementation of the NGSS in their schools and classrooms. School and district leaders gave directives regarding implementation of the NGSS but provided few or no resources to support the implementation. Many teachers reported using old textbooks and curricula that did not align with the NGSS, and none reported having books that aligned with the NGSS. These conditions created challenges and tensions for teachers. As one teacher shared, "We are struggling with finding a happy medium for moving into the Next Generation Science Standards without the information we need to do it." Overall, teachers reported having access to the NGSS standards and little more than that.

Teachers saw their limited science knowledge as a barrier. This constraint manifested itself across content knowledge and pedagogical knowledge. Some teachers suggested that they "would like to understand the content" and others cited lack of knowledge in specific areas: "I don't really understand electricity and magnetism myself, so it is hard to teach it." Others were concerned about pedagogical approaches: "There is always the bigger factor of how can I teach this efficiently, how does it look in the classroom, are the students going to manage themselves well?" Teachers also expressed how the lack of knowledge impacted their confidence and comfort with teaching science: "You feel like you are going to teach it wrong, teach it incorrectly. The idea of 'I don't want to do any harm here; I don't want to get it wrong' because if kids learn something wrong…there's a misconception there that is hard to undo." Here we see where lack of confidence may tie in with reduced science instructional time, as noted above. The challenge of knowledge was also complicated for teachers who were changing grades and had to learn new content, as well as the changes in content by grade ushered in with the NGSS. In the cases above we see well-intentioned teachers desirous of teaching NGSS-aligned science constrained by their limited content knowledge as well as NGSS-aligned instructional approaches.

Looking at the numerous constraints that teachers encountered, we see that they varied markedly across rural schools and teachers. Although limited time and lack of materials were reported by most teachers, individual needs for time and materials reflected site-specific or teacher-specific needs. Whereas almost all teachers were limited by old and outdated textbooks, the types of materials they needed depended on the types of science kits or curriculum they used. Although almost half of the teachers reported a lack of knowledge as a constraint, other teachers reported high levels of comfort with both science content as well as science pedagogy. Thus, we are reminded of the different individual backgrounds and teaching contexts of these teachers, and the wide variation in their schools and communities.

Conclusion and Implications

In this study we sought to identify and detail affordances and constraints to rural elementary teachers' enactment of science instruction aligned with the NGSS. We found that rural elementary teachers encounter a myriad of affordances and constraints as they attempt to teach science. We also found that some affordances and constraints are broad-based across varied rural settings, whereas others are more localized. Our findings build on those of other scholars who have studied affordances and constraints of rural settings more broadly (Glover et al., 2016; Goodpaster et al., 2012; Hellsten et al., 2011). Our study sheds additional light on specific challenges faced by rural elementary teachers committed to teaching NGSS-aligned science, as well as challenges that take place when new standards such as the NGSS are introduced. The majority of the themes we identified relating specifically to NGSS implementation in rural schools have been raised as challenges by researchers examining rural school settings broadly (Avery, 2013). In this study, some additional nuances specific to the different rural contexts examined, at the time of NGSS implementation were revealed.

We saw a contrast between schools with access and proximity to locations and agencies such as the Forest Service and universities and those schools that were not located near them. This affordance was primarily geographic and independent of school or district size. A number of schools were near rivers and other bodies of water that were often tied to fisheries and local economies. Outside resources were then leveraged by local schools to engage students in relevant and hands-on science activities that were more likely to be aligned with NGSS instruction. Because these resources were outside of the schools, their availability was also connected to resources related to universities, the Forest Service, and local organizations. Thus, sometimes they became unavailable to teachers who wanted to continue to use them. Nonetheless, outdoor resources provided opportunities for teachers to develop rich instruction that was engaging relevant to their students.

In terms of district and county supports, we saw the importance of science specialists. In this instance, teachers from larger towns as well as more remote rural areas were able to take advantage of the knowhow of specialists. Use of these resources appeared to be largely predicated to district and county priorities and their commitment to specialists. Some of the smaller schools, especially those located in small districts serving a few hundred students, were able to connect with county level specialists.

Some larger districts were able to hire specialists that became hubs for their schools. Larger districts were also able to bring teachers together and form district level PLCs that then created curriculum and brought it back to their schools. We did not see this affordance in smaller districts that often appeared to rely on textbook based and highly prescriptive curriculum.

We saw how the introduction of language arts and mathematics standards (CCSS) undermined and constrained science instruction generally and NGSS-aligned instruction specifically, which, from a policy perspective, was situated as a secondary priority in most of the districts. We are also mindful that the study took place in rural California, where districts are funded at a rate of approximately $1000 less per student than the national average (Showalter et. al., 2019). Larger districts were able to mitigate some of these challenges through specialists as noted above, as well as pooled resources available at the district level, such as science kits. However smaller districts were at a disadvantage by not having the critical mass to pool and share resources.

We note one important area that has been raised as an affordance for teaching science in rural settings, that was not raised by our participants: the role of students and their funds of knowledge and rich backgrounds that could be used as springboards for NGSS instruction (Kassam & Avery, 2013). Specifically, teachers did not note or leverage the rich experiences and knowledge their students may have had about local rivers, forests, or fisheries which are part of their everyday lives. Prior studies have shown the transformative impact on students and teachers that more place-based culturally connected and relevant science instruction can have (Bryan & Allexsaht-Snider, 2008; Chinn, 2008). Future studies could build on this finding by exploring why teachers do not build on local knowledge. We conjecture that some of this may be a result of teachers not being from the communities they teach in, as well as the broader challenge with implementing NGSS in ways that are culturally responsive to local communities.

We raise two considerations for those seeking to improve NGSS-aligned elementary science instruction in rural schools, especially at times of shifting policy mandates. First, we note that a variety of forms of professional development were identified as affordances and could be used to mitigate constraints such as lack of curriculum. Thus, one conclusion we draw from the findings is the potential of flexible professional development approaches that provide more targeted support to rural teachers based on individual and local needs. Given the physical isolation of most rural schools, online professional development may be particularly useful in supporting rural elementary science instruction. Second, we note the role that some school leaders played as mediators for affordances, thus limiting or mitigating challenges. Stability and support from school leadership were contrasted with the challenge of the discontinuity in leadership associated with constraints experienced by some teachers. This finding highlights the importance of strong leadership within rural schools and leads to questions about not only principal leadership but also the potential of developing leadership within schools and districts through science specialists, whom many of the teachers reported as helpful.

We conceptualize professional development support in two different ways: first, in terms of the content or substance of the program, and second, in the instructional approach of the program. The substance of professional development ranged from programs that focused on particular instructional approaches or strategies, to programs that focused on one unit of instruction, to programs that addressed approaches to science more broadly. This wide variety of professional development viewed as affordances by teachers suggests that different teachers found different types of professional development content useful, based on their particular settings and needs. For example, the professional development that focused on life cycle of salmon was most salient to those teachers who were located near rivers in which salmon were fished but was less relevant to those who were not near such rivers. Our findings support the notion that identifying local needs and local contexts for science instruction prior to designing or implementing professional development programs may lead to more productive learning opportunities for teachers. This approach also moves away from one-size-fits-all approaches that may seem more attractive in their broad appeal, but ultimately would only serve a small proportion of teachers. The types of professional development teachers reported as productive ranged from local support through PLCs to off-site programs which included those conducted by expert teachers, scientists, or university faculty as well as programs facilitated through technology. The PLC approach seemed most productive and perhaps best suited to reduce the isolation experienced by many of the teachers. It is clear that resources were not equally distributed across schools and districts, and the PLC approach may mitigate this inequity. Through pooling resources, counties and different districts or schools may offer a range of professional development that meets a wide range of teacher needs. The use of technology and PLCs could work to create communities of learners especially for teachers in remote and smaller schools. Alignment with NGSS across all professional development areas would facilitate coherence between grade levels, school sites, and across different professional development programs. Further examining PLCs or designing PLCs in rural settings and studying their challenges and how they work to improve participating teacher persistence, identity, and instruction could shed light on a potential area that could be a high impact lever to improving science instruction in rural schools.

All the rural schools in our study were constrained by instructional mandates guided by standards such as the CCSS and the NGSS. The ways in which those constraints were addressed varied according to the availability of local resources as well as how principals managed those resources. In some cases, principals facilitated access to professional development, provided funds for purchasing materials, and provided teachers with the policy landscape which drove school-level decisions. In other cases, principals appeared to be disconnected or overwhelmed and provided little support to teachers. In contrast, some teachers in schools with significantly limited resources reported being supported by their principals. We conjecture that this was due to the transparency that some principals provided to their teachers when explaining conditions and constraints beyond their control. This transparency led to acceptance from the teachers rather than an expectation for immediate change. This finding suggests that transparency and a clear vision communicated from a principal can mitigate some constraints and may be nearly as important as the supports that principals can provide. The leadership component appeared to operate independently of district and locale factors, and further investigating how and why particular principals were more supportive would be helpful to determine how to support implementation of new instructional initiatives such as NGSS.

As the current project continues, we plan to examine more closely how varied types of affordances differentially impact teachers' science instruction. Given the constraints, especially resource-centered constraints as noted above, we plan to examine how the use of moderate supports such as virtual PLCs, sharing of NGSS-aligned resources across a broad range of media such as newsletters and websites, and providing small amounts of lab materials impact rural teachers' NGSS-aligned instruction.

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Suggested Citation:

Zinger, D., Sandholtz, J. H., & Ringstaff, C. (2020). Teaching science in rural elementary schools: Affordances and constraints in the age of NGSS. *The Rural Educator, 41*(2), 14-30. https://doi.org/10.35608/ruraled.v41i2.558