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RESEARCH ARTICLE

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Education researchers as negotiators: Leveraging expertise across teachers and scientists to implement authentic data investigations in grade 7–12 classrooms

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Abstract
Incorporating authentic research skills and practices into K-12 science, technology, engineering, and mathematics (STEM) instruction is a challenging yet crucial approach for introducing students to authentic science inquiry. While recommendations for emphasizing data literacy and quantitative reasoning in science classroom contexts are well-established, implementation remains challenging. Over the span of 4 years (2019–2023), a multi-institution team of teachers, education researchers, and forest scientists established a partnership with the overarching goal of integrating authentic forest research and data into middle and high school classrooms. The education researchers played a critical role in facilitating effective scientist and teacher interactions while addressing classroom implementation challenges. Importantly, the effectiveness and mutual benefits of the research partnership were greatly influenced by specific practices implemented by the education research team, and the assumption of different collaborative roles by all stakeholders involved. In this study, we examine these roles, relationships, and interactions of all stakeholders in the partnership, with "stakeholder" referring to participating teachers, education researchers, and collaborating forest scientists.

1 | BACKGROUND LITERATURE

During the last decade, including authentic research and opportunities for students to grapple with real-world data has gained traction among the K-12 STEM education community as a strategy to improve students' data literacy and quantitative reasoning skills (e.g., Gould et al., 2014; Kjelvik & Schultheis, 2019; Mayes et al., 2014). Developing these skills and competencies within authentic contexts is particularly relevant in a modern world where data permeate every aspect of human life. Engaging students in authentic research might range from working with published research data, collaborating with scientists on research projects, or designing and carrying out classroom-based research projects. However, this can be a challenging task for many teachers. For example, research findings may be difficult to comprehend or relate to for students, and working with complex data requires sophisticated reasoning skills that students and teachers may lack (Bopardikar et al., 2023; Schreiter et al., 2024; Schultheis & Kjelvik, 2020).

Teachers may also struggle to provide students with opportunities to engage in authentic research projects with "real" scientists in the field, with research instead often presented in classroom settings after the study findings are disseminated (Bhattacharya et al., 2020; Monroe et al., 2017). Yet engaging students in authentic research practices through classroom collaborations with scientists has demonstrated benefits, including equipping students with transferable workforce skills, enhancing problem-solving and critical thinking abilities, and increasing positive attitudes toward STEM and STEM-related careers (Habig & Gupta, 2021). Students are not the only beneficiaries, as scientists have demonstrated increased pedagogical knowledge (MacFadden et al., 2022), and teachers can develop enhanced science content knowledge by engaging in collaborative research partnerships (Aristeidou et al., 2023; Dresner & Worley, 2006). Research collaborations are also valuable in creating communities of practice for teachers to share ideas, strategies, and challenges with one another (Aristeidou et al., 2023; Dresner & Worley, 2006). To address the challenges of integrating authentic research into classrooms, teachers need support developing their own quantitative reasoning and data literacy skills and fostering productive student-centered research partnerships with scientists in the field.

This project leveraged data from climate change research about forest ecosystems as a compelling and accessible way for teachers and students to participate in authentic research. In New England, forests are a primary ecological and economic driver, with a long history of service to rural communities that strongly depend on their health (U.S. Bureau of Economic Analysis, 2018). The Northern forests are relatable and accessible to all students from this region, and current climate-centered forest research focuses on many emerging complex and dynamic challenges (e.g., Contosta et al., 2019; Guilbert et al., 2015; Reinmann et al., 2019). Collaborations with forest scientists open new avenues for integrating quantitative reasoning and data literacy skills into the curriculum, including exposing students to how scientists use data for evidence-based decision-making.

1.1 | Theoretical framework

Scientists and teachers partnering is not a novel practice; multiple studies cite such collaborations, including in professional development settings emphasizing inquiry in instruction (Caton et al., 2000), citizen science initiatives (Bopardikar et al., 2023; Falloon, 2013), or to enhance the broader impact goals of scientific research (Warwick et al., 2020). However, recent studies have identified an assumed power dynamic within scientist–teacher collaborations that implies a one-way flow of knowledge-sharing where scientists alone are positioned as experts, and teachers are positioned primarily as learners (Atias et al., 2023; Shanahan & Bechtel, 2019). These studies call for more equitable participation across stakeholders, which aligns with recommendations for best practices within research–practice partnerships (Henrick et al., 2017, 2023; Warwick et al., 2020). The present study examines the implementation of, and outcomes from, a more equitable participation structure designed and facilitated by education researchers.

To assess the collaborative nature of this project, the research–practice partnership (RPP) literature provides a useful framework. Henrick et al. (2023) describe five dimensions of successful RPPs: (a) Cultivate trust and relationships; (b) Engage in inclusive research or inquiry to address local needs; (c) Support practice or community organization in making progress on its goals; (d) Engage with the broader field to improve educational practices, systems, and inquiry; and (e) Foster ongoing learning and develop infrastructure for partnering (Table 1). Within each dimension, the authors provide indicators that serve as benchmarks to evaluate partnership work (Cooper et al., 2021). Examining our partnership work in light of these indicators can inform future collaborations by identifying best practices and lessons learned.

Within collaborative spaces that engage both researchers and teachers, each participant can assume a variety of roles during project work, including what Cooper et al. (2021) characterize as "strategic roles," that can greatly influence project structures and personnel dynamics. A 2006 framework by Drayton and Falk outlined five roles that research scientists can assume when working with science teachers, including co-developer of curriculum, deliverer of content, visitor to classroom, scientist–student partner, and teacher mentor. This framework is commonly referenced across the literature examining scientist–teacher collaborations (e.g., Atias et al., 2023; Bopardikar et al., 2023; Falloon, 2013) and offers a helpful lens through which to explore the stakeholder interactions within such collaborative spaces, while also informing which indicators from the RPP framework (Henrick et al., 2017, 2023) are being addressed. Therefore, we sought to examine how the RPP and roles frameworks described (Drayton & Falk, 2006; Henrick et al., 2017, 2023) mapped to real-world practice within the context of our collaborative work and related research. The following questions serve as a framework for this research study:

1. What did stakeholders identify as essential for successful collaboration among teachers, education researchers, and research scientists while advancing research goals? (RQ1)
2. Which roles did all stakeholders assume during these interactions? (RQ2)

TABLE 1 RPP dimensions and indicators from Henrick et al. (2023).

Dimension	Indicators	
1	1A	Work together
	1B	Follow through
	1C	Value diverse perspectives
	1D	Navigate conflict
	1E	Interrupt problematic power and privilege dynamics
	1F	Invest in one another's welfare
	1G	Navigate broader demands and constraints
	1H	Acknowledge context and history
2	2A	Design research questions that prioritize local needs and context
	2B	Include relevant perspectives in developing research or inquiry questions
	2C	Engage in research or inquiry for action
	2D	Balance rigor and feasibility
	2E	Invest adequate resources and capacity
	2F	Include relevant perspectives in the research and inquiry process
3	3A	Align goals with the priorities of the practice/community organization
	3B	Include relevant perspectives and authority in goal setting and revising
	3C	Align work with the local context
	3D	Learn together through collaborative sensemaking
	3E	Inform decision-making with ideas from research
	3F	Advance the practice/community organization's goals
4	4A	Include relevant perspectives in decision to share knowledge
	4B	Identify what is useful to share and with whom
	4C	Design and facilitate sharing collaboratively
	4D	Engage diverse audiences to share knowledge
	4E	Recognize partnership knowledge as co-created
5	5A	Engage from a learning stance
	5B	Develop new skills, knowledge, and identities for partnership work
	5C	Plan and revisit strategies, practices, and roles to meet goals
	5D	Attend to the health of the partnership
	5E	Garner organizational support

2 | METHODS

2.1 | Project context

The multi-institution research project, spanning 2019–2023, aimed to investigate the resilience of northern forest ecosystems through novel big data acquisition, informatics, integration, analysis, and modeling. The interdisciplinary project was organized across four integrated teams: Advanced Sensing, Environmental Informatics, Ecological Modeling, and Quantitative Reasoning in Context (QRC). The QRC team consisted of grade 7–12 science teachers, research scientists, and the QRC leadership team of education research faculty from three institutions and staff from a STEM education research center at one of the universities.

Professional learning meetings consisted of annual in-person summer institutes from 2021 to 2023, which lasted for four full days each summer, along with monthly virtual 90-min meetings during the academic year (see timeline and major activities in Figure 1). The summer institutes took place at Schoodic in Acadia National Park (2021), the University of Maine (2022), and the University of Vermont (2023), and all stakeholders were provided with lodging. Teachers formed working groups at the first summer institute based on shared classroom goals and continued to work closely with their collaborative group throughout the project, both during official

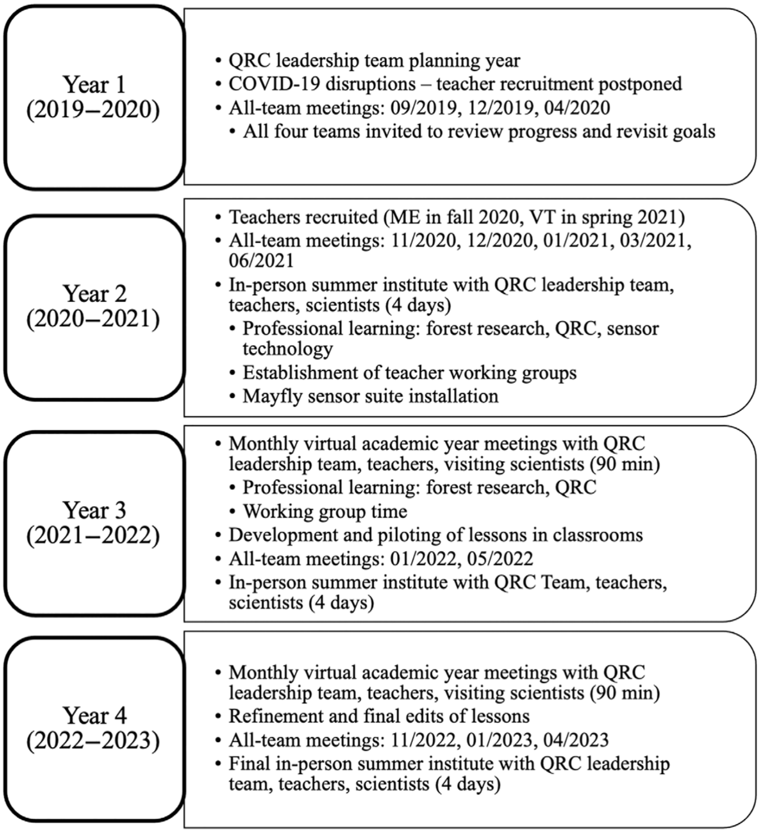

FIGURE 1 Project timeline outlining major QRC team activities. The COVID-19 pandemic disrupted original teacher recruitment timelines and some major project activities, including researchers observing classrooms during lesson implementation. Virtual or outdoor classroom visits were employed instead. Project teams included Advanced Sensing, Environmental Informatics, Ecological Modeling, and Quantitative Reasoning in Context (QRC).

project meetings and on their own as reported by teachers during meeting check-ins.

2.2 | Participants

The QRC leadership team included 10 members across the duration of the project, including five university faculty members specializing in education research and five staff members from a STEM education research center. Leadership team members' education research experience ranged from 3 to 20 years; all were female. Thirteen middle and high school science teachers, five from Maine and eight from Vermont, were selected based on application responses across several criteria including their indicated interest with working with data, plans for incorporating project work in the class, whether they had interest and/or prior experience in forestry science, and their enthusiasm for collaboration and fieldwork. Their teaching experience ranged from 1 to 21 years and included 5 males and 8 females. Six forest scientists (3 males, 3 females) across the Advanced Sensing, Environmental Informatics, and Ecological Modeling teams collaborated with the QRC leadership team and teachers in program development and implementation throughout the project. Scientists' professional positions ranged from postdoctoral researcher to full professor; they self-identified as interested in collaborating with the QRC team during the initial project meeting in December 2019 (Figure 1). Other scientists and graduate students were invited by the QRC leadership team to support teachers in their learning and curriculum development as the need arose.

2.3 | Data sources and analysis

Multiple data sources informing the planning, goals, implementation, and impacts of the QRC team project activities were used, such as leadership team planning notes, meeting agendas and slides, exit slips, and stakeholder interviews. Institutional Review Board approval was obtained for all recruitment, informed consent, and data collection protocols, and pseudonyms replaced all participant names.

Planning notes documented the decision-making processes involved in the development and implementation of the professional learning and the research plan. Meeting agendas, slides, and exit slips were employed at every professional meeting with participating teachers. Slides and agendas covered professional learning content and provided space for teacher working groups to document their ideas and learning, whereas exit slips asked teachers for feedback and reflections on sessions or topics.

Teachers could answer these anonymously or provide their names for follow-up. For summer institutes, exit slips were administered after each day's activities. All exit slip questions were developed by the project team and included items such as "How valuable was this meeting for you?" and "What additional knowledge or supports would be helpful for your working group in planning your learning experience(s)?"

All interview protocols were developed by the project team. Annual semi-structured interviews were conducted with Maine teachers to document experiences using QRC and forestry explorations in their classrooms prior to and during their involvement in the project. Initial interviews included items like, "How often do you work with data with your students?" and "How does working with data benefit your students?" Subsequent interviews were intended to capture details about the learning experiences as they developed, including questions such as, "Do students gather data during this learning experience or do you provide them with prepared data?" Due to research team capacity constraints, Vermont teachers were not interviewed annually; however, the final year's exit interview protocol included holistic reflection questions that Vermont teachers were invited to answer (e.g., "What supports were most helpful for you in developing and implementing the learning experiences for integrating QRC and forestry in your classroom?" and "How do you see this work continuing in your classroom in the future?").

Both QRC leadership team members and scientists who had participated in some collaborative capacity with the QRC team and/or teachers over the project's lifespan also participated in exit interviews during the final year. These interviews asked scientists to reflect upon their contributions to professional learning activities and lesson development, as well as their perceptions of the benefits of teacher–scientist collaborations. Example questions from these interviews included "What was your role in working with the Theme 4 teachers on this project?", "How would you define a successful teacher/scientist collaboration?", and "What considerations do you think are important for scientists to think about when communicating their work to a broader audience who may not have a scientific/technical background?"

2.3.1 | Professional learning: Indicators and roles coding

Professional learning data (meeting notes, slides, exit slips) were examined for all instances of direct stakeholder interactions and coded for relevant RPP dimensions and indicators (Henrick et al., 2017, 2023). Planning notes from QRC team meetings provided additional context, including decision-making around meeting facilitation and structure, to further inform coding decisions. Initial analysis was completed using the Henrick et al., 2017 RPP framework; upon publication of the updated framework (Henrick et al., 2023), all analyses were reviewed against the revised indicators to verify our results, with adjustments made as appropriate. To record this process, all meetings were compiled into chronological order in a spreadsheet with a summary of attendees, topics covered, and links to any relevant agendas, meeting notes, and/or exit slips. Scientist roles (Drayton & Falk, 2006) were coded concurrently; corresponding roles for the teachers and education researchers were also created and aligned to each scientist role to provide clarity for all participants involved, then coded as well. All indicators and roles were recorded in adjacent columns for each session, with memos included to indicate each researcher's reasoning (Figure 2). Two education researchers contributed to the analysis, and after all non-interview data sources were reviewed, the alignment was discussed to establish consensus and add additional context. The resulting spreadsheet included all indicators and roles and was examined holistically to identify emerging patterns or themes.

2.3.2 | Interview coding

All interviews were recorded and transcribed, with transcriptions de-identified using pseudonyms and analyzed using a sequential, open coding process informed by grounded theory (Corbin & Strauss, 2015; Miles et al., 2018). Interviews were coded by three education researchers using qualitative analysis software (Dedoose v.9.0.90). Grounded theory was understood to be aligned with Strauss's conceptual framework, as described by Corbin (2013), in which in-vivo codes were generated based on interviewee responses and refined or collapsed into larger categories throughout the analysis process. For intercoder reliability, one teacher and one researcher interview were coded by three team members individually with about 80% consensus. After reviewing the coding schema, the team discussed, collapsed, refined, and reorganized inductive codes as necessary to reach a consensus of 90% (Figure 2). Every interview was reviewed against the final codebook. The initial deductive codes were based on the Henrick et al. RPP framework (2023), with inductive codes applied iteratively. Scientist roles (Drayton & Falk, 2006) and the corresponding roles for both teachers and QRC leadership members were also included to identify the various ways in which all stakeholders reflected on their interactions during different

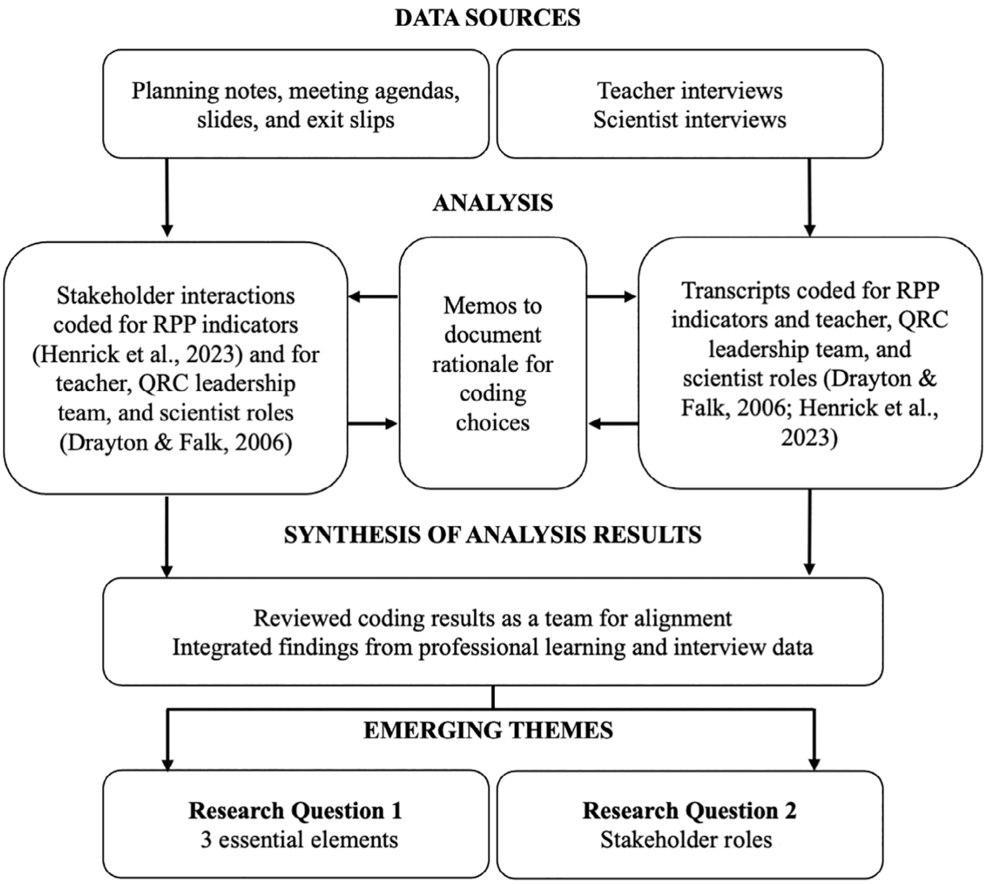

FIGURE 2 Data analysis process.

stages of the project. Because the authors were part of the QRC team (and indeed, some interviewees were QRC team faculty members interviewed by a non-faculty research team member), we were also aware of the role our backgrounds and beliefs played in shaping project activities; thus, a constructivist coding approach (Charmaz, 2016) that included acknowledgment of these roles was appropriate to apply to the interview data.

3 | RESULTS

Synthesized analysis across all data sources identified three essential elements for successful collaboration among the QRC leadership team, project scientists, and teachers. These elements were (a) negotiation practices employed by the QRC leadership team; (b) the creation of equitable participation spaces for all stakeholders; and (c) positioning teachers as expert contributors. These essential elements were closely associated with the implementation challenges of integrating authentic research into classrooms. Coding analysis across all data sources revealed an evolution of RPP framework indicators associated with these key elements, as well as changes in distinct stakeholder roles across project years. All coding results discussing RPP indicators below are in reference to the Henrick et al. (2023) framework (Table 1).

The results of coding the RPP dimensions and indicators to all professional learning activities, such as the summer institutes (SI) and the academic year (AY) meetings, show a strong emphasis on dimension 1 ("Cultivate Trust and Relationships") (Figure 3). During the first SI, nearly 93% of all indicators coded were from dimension 1, indicating the importance of creating strong relationships between stakeholders to form a robust foundation for collaboration. It remained the most-coded dimension throughout the project, with every indicator mapped across multiple sessions. Dimension 1 was also the primary dimension represented in interview data, representing 42% of all coded indicators from scientists and QRC team members' interviews and over 33% for teacher interviews.

During the 2021–2022 AY meetings, dimension 3 ("Support Practice or Community Organization in Making Progress on its Goals") was coded in more than 23% of the activities, with a strong emphasis on collaborative sensemaking in working group time. The rise of dimension 3 codes continued during the 2022 SI to more than 27% of the summer activities. Dimension 5 ("Foster Ongoing Learning and Develop Infrastructure for

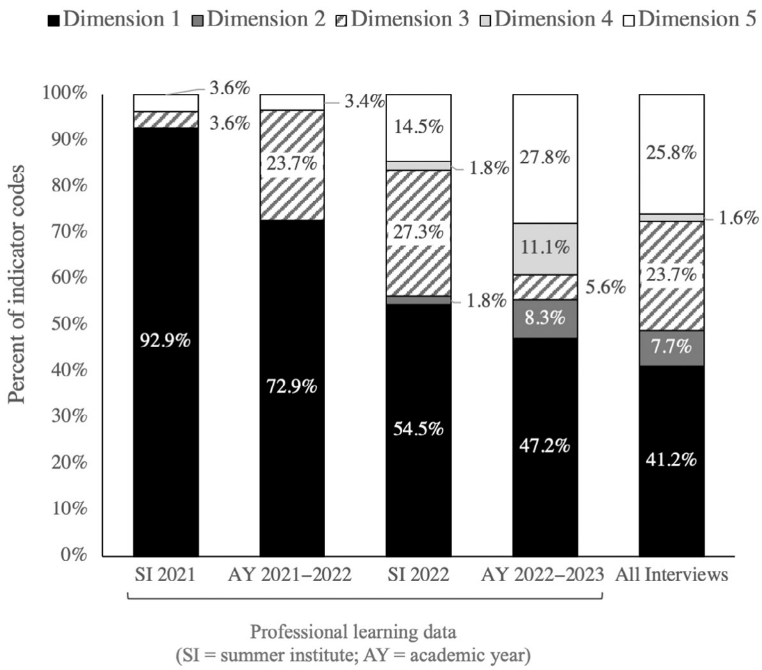

FIGURE 3 RPP dimension coding results from professional learning and interview data. Professional learning data include meeting slides, agendas, note documents, and exit slips from summer institutes (SI) and academic year (AY) meetings. Percentages represent indicators within a specific dimension out of all indicators coded for the given dataset. RPP dimensions are those defined by Henrick et al. (2023) and listed in Table 1.

Partnering") also began to appear more frequently and was mapped to more than 14% of the activities. In the final year of the project, dimension 5 became the second most-coded dimension, making up over 27% of the codes for the final 2022–2023 AY meetings. The interview data displayed similar results, with dimensions 3 and 5 also showing up as second or third most-coded themes (Figure 3). QRC team members referred to dimension 3 related activities more than dimension 5, whereas scientists and teachers mentioned more activities related to dimension 5.

3.1 | Essential element 1: QRC leadership team negotiation practices

Navigating and aligning the needs and goals of project stakeholders was a challenging process and a major focus of the QRC leadership team. During data analysis, initial inductive codes and memos describing this process included terms such as "navigation," "facilitation," "translation," and "interpretation," which were ultimately collapsed into the "negotiation practices" code. One such negotiation practice employed by the QRC team was active listening; examples discussed in interview data mapped to RPP dimensions 1C ("Value diverse perspectives"), 3D ("Learn together through collaborative sense-making"), and 5A ("Engage from a learning stance"). Within excerpts coded with these RPP indicators, *language* emerged as an important theme from QRC leadership team interviews, with one team member noting,

> […] When we go from one field to the next […] the way we describe concepts can be completely different, and it's not uncommon that there is a conversation or a discussion that lasts for about 30 min, until we finally figure out that we were all agreeing all along. But the language was just different […].
>
> (Tara, QRC Leadership Team)

Similarly, another QRC leadership team member stated, "I think one of the challenges that became clear to me is the challenge of language and making language accessible and explaining it," (Isobel, QRC leadership team). Therefore, eliciting ideas from all stakeholders by collecting questions and comments through facilitation routines was a vital practice for every meeting. These routines included sending out agendas with action items, having a working slide deck where stakeholders were prompted to document discussions and progress, and closing every meeting with an exit slip to inform future planning. Through active listening and navigating these language challenges, the QRC team positioned itself well as negotiators between scientists and teachers to meet the project goal of integrating authentic research into classroom learning.

Other negotiation practices were captured in QRC team meeting notes from early planning efforts well before scientists from other teams were scheduled to participate in teacher meetings. At the first all-team retreat in December 2019, QRC leadership team members engaged with forest scientists to understand their respective research goals to anticipate how their expertise could be leveraged in the future to meet teachers' needs as classroom goals were developed. Meeting notes from these sessions reflected the QRC team's emphasis on their role as “interpreters/purveyors” of “what is science” and “what do scientists do” to connect scientist teams to the students and teachers who would be participating (QRC Team all-team retreat notes, December 18, 2019).

Another negotiation practice that emerged from interview data was the QRC team's structuring of knowledge-sharing sessions between scientists and teachers to navigate and align the needs and assets of each stakeholder group. Importantly, this process was not accomplished by merely convening stakeholders and assuming needs would be met. As noted by Isobel:

> I think that one of the challenges our teachers were identifying as okay: [...] We want to have scientists come and talk to our students, but we don't want them to overwhelm the students. And so we were talking about, well, how do you prompt the scientists to give you what you want and need for your students? So how do you, the teacher, play that role of educating the scientists, when you don't feel like you are on equal footing, necessarily in terms of the science content? Does that make sense? So, for me that's been an important lesson.
>
> (Isobel, QRC Leadership Team)

RPP indicator codes from this excerpt reflected these negotiation efforts of the QRC leadership team, including 4B (“Identify what is useful to share and with whom”) and 5B (“Develop new skills, knowledge, and identities for partnership work”). During the academic year meetings in which scientists were invited to share knowledge and resources with teachers, the QRC team continued to guide scientists to model content and presentation styles in ways applicable to classroom settings, reflecting RPP indicator 1G (“Navigate broader demands and constraints”). For example, the QRC leadership team intentionally encouraged short presentation formats mirroring the scientists' graduate student talks to allow for extended discussion, offering a more informal yet constructive space for teachers to probe scientists' expertise. This style differed from the professional presentations scientists were used to and prompted them to package their information in new ways, as noted by forest researcher Michael:

> So, I think using this opportunity to learn, you know, about how to educate effectively at the level that those teachers are educating at so that you can have the most impact with what you're trying to deliver. I think it's pretty really enriching in terms of like, how do I package this information for a different audience?
>
> (Michael, Ecological Modeling Scientist)

Codes from this excerpt included 3D, 4B, 5A, and 5B, reflecting the impacts of this negotiation practice on the scientists themselves.

3.2 | Essential element 2: Creating equitable participation spaces

The second essential element in the collaboration process, creating equitable participation spaces for stakeholders, was noted across several examples during data analysis. Equitable participation spaces were identified primarily through specific RPP indicators and roles applied during coding that emphasized disrupting power dynamics and shared decision-making processes. One notable example occurred at the first summer institute, where teachers and scientists installed a Mayfly sensor suite in the field. During this process, all participants collaboratively determined the best plot location and installed it as a team, rather than ceding all decision-making power to the scientists. Coding data from this session highlighted several indicators across RPP dimension 1 that reflected this equity approach, including 1A (“Work together”), 1C, and 1E (“Interrupt problematic power and privilege dynamics”). All 13 teachers expressed on exit slips that this session was “Valuable” or “Extremely Valuable,” indicating their appreciation for being partners in the decision-making in the field.

Certain academic year meetings also emerged through coding analysis as critical equitable spaces, particularly those designed for building a shared understanding of what was feasible to accomplish at the intersection of forestry research and classroom practice. At the November 2021 meeting, several forest and education researchers were invited to speak with small, self-selected teacher groups about carbon cycling, statistics, quantitative reasoning, and sensor data collection. Coding results from meeting notes and slides indicated the structure of this meeting allowed for teachers and scientists to exchange various viewpoints and ideas (1C), which created a space for mutual understanding of participants' expertise (1H, “Acknowledge context and history”) and shared learning about what kinds of authentic research integration were possible in classrooms (3D). Importantly, teachers were given the agency to seek what they needed, without scientists nor the QRC team assuming what would be useful for the teachers' learning experience development (1E). Exit slips from teachers and scientists alike indicated this was a useful exercise, with one teacher saying having the scientists present was "most helpful in answering my questions" and a scientist saying they could, "think more specifically about how [to] share our current research efforts and data with the teachers."

Scientists' reflections in interviews about how they had learned from teachers also served as a measure for identifying equitable participation spaces, with two scientists observing different instances of interactions with teachers being informative for their work:

> ...Being able to [...] observe the teachers [at the summer institutes] and being able to learn from them there- that's another big part. And I felt like the project did a pretty good job of having this two-way communication between the scientists and the teachers, and being able to say, you know, "This is how we implemented this in our classroom." And scientists being able to learn from that data and being able to learn from what's happening in that classroom, and what else [the teachers] might have for needs from scientists.
>
> (Ivy, Ecological Modeling Scientist)

> One of the big things was getting different perspectives, or having people ask questions that maybe a scientist isn't asking me. But it's something that I should think about... when I gave a talk I don't know, like a year ago with [the QRC team], someone was [...] asking about how we're defining a cold air pool. And can you get an inversion that's not from cold air pooling? Like some really simple stuff to think about, but like it's actually a really good question, and it made me then kind of look into the literature and say [...] How are we defining this really? [...] So I feel like sometimes having someone who is not deep into it asking questions from these other perspectives is helpful to me and my science.
>
> (Anna, Advanced Sensing Scientist)

Ivy's reflections on the exchange of knowledge were coded with RPP indicators 1A, 1E, 1H, and 5A as she explicitly mentions teachers' classroom knowledge and experiences informing how scientists can approach integrating their research and classroom practice in the future. Similarly, Anna mentions that collaborating with teachers on the QRC team affected her understanding and thinking about her forestry research; indicators 1C, 3D, 5A, and 5B reflected this shift in thinking. Importantly, these excerpts and indicators collectively point to not just a sharing of ideas, but meaningful shifts in approach for research and collaboration work, suggesting these scientists viewed teachers as equitable thought partners.

Interview data also indicated the process of breaking down power dynamics (RPP indicator 1E) was an important step in building an equitable project approach. In responding to a question about what scientists should consider when communicating their work to a non-expert audience, one scientist underscored the importance of "being vulnerable,":

> I don't know, it is being willing to be vulnerable, like sometimes teachers and students will ask you things and you're like, "I don't know." You know? I think that you know often there is this feeling of like, "I have to be the expert. I'm the one with the PhD. I should have it all figured out and if I go into a setting with a bunch of students and a teacher, and they start throwing these curveballs at me [...]" So being okay with that, I think is important.
>
> (Olivia, Advanced Sensing Scientist)

RPP indicator codes associated with this quote included 1C, 1E, 1G, 3C ("Align work with the local context"), and 5B, due to Olivia's explicit acknowledgment of a tendency for scientists to uphold a power dynamic of "scientist-as-expert" when visiting classrooms and sharing research work. However, authentic science is a much messier process, and embracing a "vulnerability approach" could be one way to break down such dynamics and empower students and teachers to more fully contribute to and participate in authentic inquiry.

3.3 | Essential element 3: Positioning teachers as experts and scientists as learners

The third essential element identified in data analysis was explicitly positioning teachers as experts and scientists as learners. As lesson materials were developed, teachers' requests during professional learning meetings and on exit slips became more focused on specific resources needed to help move their work forward. There was one particular ask from teachers—authentic data curated for classroom use—that emerged as a repeated request. Simply providing teachers with datasets acquired from the scientists was not sufficient and often not classroom-applicable. Coding data indicated that considering specific classroom realities (3C) and teacher expertise (5B) were critical in bringing authentic data to the classroom. For example, one teacher noted challenges many students face when working with spreadsheets, a common format for scientific analysis:

> Because I was providing [the dataset] to my honors biology students who are sophomores, and they didn't have a lot of experience working with spreadsheets at all. So, I want to try and, you know, just give them one new thing at a time or to minimize it because it just gets overwhelming, and then they shut down and get lost in some of the other details. So, I figure it's nice to kind of go stepwise.
>
> (Mary, Teacher)

This insight echoed by multiple teachers was crucial for the project team to consider when attempting to fulfill the request for authentic, curated data that aligned with classroom context.

During the May 2022 professional learning session, a computer scientist from the Environmental Informatics team introduced teachers to an online platform used by forest scientists across the project for uploading, visualizing, and downloading shared spatial data as a potential platform for classroom use. While some teachers expressed curiosity and interest in their exit slips, the overall sentiment was that it was over complicated for both their own and students' use, reflecting a continued need to bridge research and classroom contexts. Interview coding data underscored the importance of co-creating resources that incorporated both scientist *and* teacher expertise, highlighting the need for scientists and the QRC team to explore this idea further (RPP indicator 5A):

> Well, and maybe that's the piece right? Maybe it's literally just, you know, how can teachers help scientists that are way up here connect those pieces, you know? … and just this idea of like, do you know what is taught in high school? […] But you know, in general, I think, like that that disconnect needs to be explored, and I think that even that is a great connection that I think any advanced scientists would be able to - or may, if it aligns with their goals - may be able to pull out of in the collaboration like this.
>
> (Marcus, Vermont Teacher)

The subsequent data curation process—that is, making authentic data from scientists readily usable for teachers and students—required the QRC team to exercise several iterations of negotiations to meet this goal. Conversations with teachers at the 2022 summer institute further clarified teachers' dataset needs and what scientists had to offer, with particular attention paid to teachers' expertise around their students' capabilities and logistics of classroom implementation. By the September 2022 academic year meeting, a draft of a curated data website that drew upon datasets collected by forest scientists was shared with teachers based on the summer institute discussions. Website features included the following: (a) a synthesis of background information and key findings from the literature to offer teachers anchor points for student analysis of specific variables; (b) differentiated datasets that offer varying degrees of attribute complexity to explore; (c) links to ready-to-graph datasets within the Common Online Data Analysis Platform (CODAP; https://codap.concord.org); and (d) links to additional background information that teachers can use to contextualize the datasets. RPP indicator codes from meetings focusing on the website development—such as 1C, 1G, 2F ("Include relevant perspectives in the research and inquiry process"), 4A ("Include relevant perspectives in decisions to share knowledge"), 4C ("Design and facilitate sharing collaboratively"), and 4E ("Recognize partnership knowledge as co-created")—highlighted bringing multiple perspectives to bear in the data curation process, demonstrating that no single stakeholder group was able to tackle this process alone.

Reflecting on the data curation process, an excerpt from one teacher's interview was coded with indicators 3A ("Align goals with the priorities of the practice organization") and 3C, emphasizing the importance of the alignment between research and practice through iterative conversations:

> Well, and when we talk about these data sets, I think that was a really good [conversation]… Like taking the data sets and converting them to more [accessible versions]… I really enjoyed that conversation … It was like, Here's the data set. A high schooler is not going to know what that like this means, right? So like very, very specific connections of like: Here's a graduate-level data set that just assumes, you know, like that type of information. And so, being able to connect those things, I think it's really important. …

TABLE 2 Corresponding teacher and QRC leadership team roles identified in this study compared to scientist roles described by Drayton and Falk (2006).

	Scientists	Teachers	QRC leadership team
Role 1	Co-developer of curriculum	Developer of curriculum	Co-developer of curriculum
Role 2	Deliverer of content in teacher enhancement (inservice or preservice) as lecturer in a course, or workshop leader	Learner	Negotiator, Workshop leader; Learner and participant
Role 3	Visitor to the classroom, or accessible to answer queries and seek resources for students, teachers, or parents.	Host/facilitator, or active resource-seeker	Negotiator
Role 4	Scientist–student (–teacher) partnerships	Observer/supporter between scientists & students as needed	Negotiator
Role 5	Teacher mentor, or provides a teacher with the opportunity to work on a research project.	Mentee/active participant in research	Research participant
Role 6	Learner	Expert	Learner

Note: Project data necessitated adding a sixth role for scientists as learners and teachers as experts.

> And it's only through getting into high school teaching that I understand so much more about the big picture.
>
> (Marcus, Vermont TEACHER)

While teachers' expertise about practical implementation logistics was a key driver in creating the data website, their expertise also influenced project stakeholders in other ways. Interview data from several scientists and QRC team members reflected the impact teachers had on their own practice, as noted by Ivy in the following excerpt:

> [Teachers] know best and know what works and what doesn't. It helps me understand, you know? Like I might have this idea in my like, science world of, "Oh, we should do this!" and then- like you get out into the classroom, and you're like, "That is not going to work." Like the teacher is usually the one who's able to say, like, "This is what's going to work." [...] So, it's an opportunity for, you know, me to connect with the teachers and to learn from them.
>
> (Ivy, Ecological Modeling Scientist)

Coding data from this excerpt included RPP indicators 1H, 3B ("Include relevant perspectives and authority in goal setting and revising"), and 5A, reflecting Ivy's acknowledgement and respect for what teachers had to offer to the collaboration. Interestingly, while scientists and QRC team members described such instances of "teachers as experts" in their interviews, teachers themselves did not mention or recognize these types of interactions. Instead, when asked about the benefits of engaging in partnership work, teachers tended to emphasize what they learned from scientists without necessarily acknowledging their own expertise.

3.4 | Stakeholder roles

Stakeholder role coding occurred across data sources from year 2 onward, representing the launch of interactions across all stakeholder groups (i.e., QRC leadership team, teachers, and forest scientists). Because the existing framework (Drayton & Falk, 2006) only articulated scientist roles, the research team created corresponding roles for teachers and the QRC leadership team (Table 2). A sixth role code—scientist as learner, teacher as experts—also emerged to characterize specific scientist–teacher interactions.

Role 2 was the most commonly coded role for all stakeholders across all professional learning sessions combined (Figure 4, dark gray bars). The remaining roles were coded much less frequently; for example, role 1 only appeared for teachers and QRC team members in professional learning data (Figure 4, black bars). There were no instances of a given stakeholder occupying role 4 during professional learning data, though this role represented 20.6% of scientist roles and 7.3% of teacher roles coded in interview data (Figure 4, light gray bars). Interview data also displayed a greater variety of roles applied to scientists and teachers as compared to professional learning data sources; however, interviews captured participants' reflections across the whole project timeline, whereas

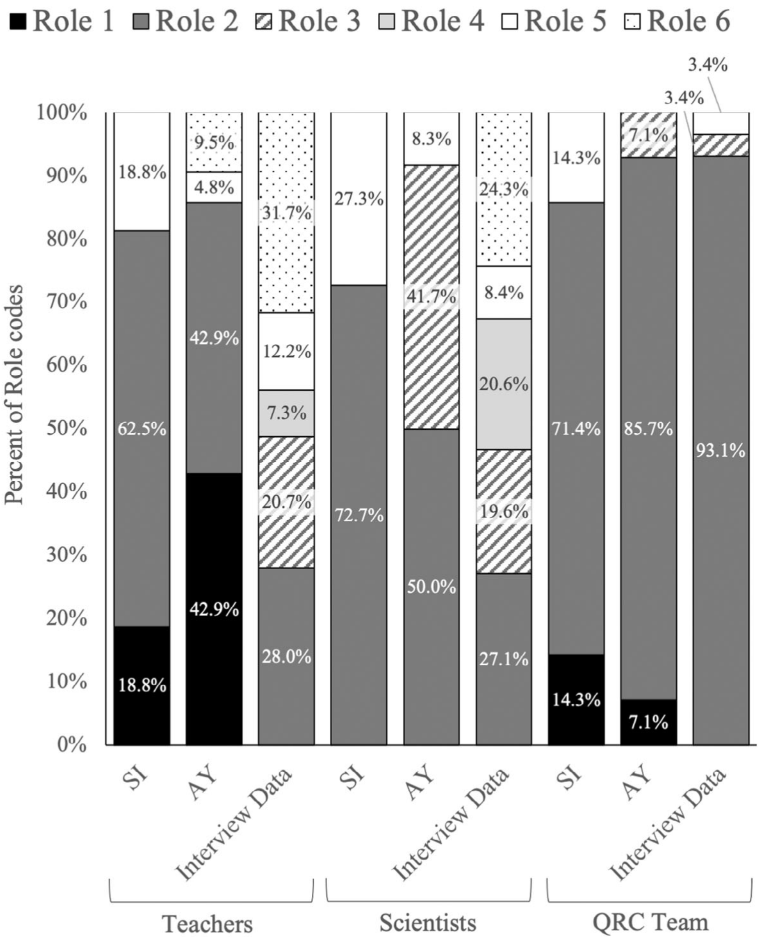

FIGURE 4 Role coding results from professional learning and interview data for all three stakeholder groups (teachers, scientists, and QRC team). Professional learning data include meeting slides, agendas, note documents, and exit slips from summer institutes (SI) and academic year (AY) meetings. Percentages represent how many codes applied within a dataset belonged to each role (e.g., for all role codes applied to teachers during summer institutes, 62.5% of them were role 2). Roles are defined by Drayton and Falk (2006) and expanded upon by the research team; see Table 2.

professional learning data were organized by specific time periods (summer institutes and academic year meetings).

Coding from professional learning data indicated that teachers engaged as curriculum developers, learners, and mentees/active participants in research (roles 1, 2, and 5) across both summer institutes and academic year meetings, with these roles shifting as teachers moved between working group time, workshops with scientists and QRC leadership team members, and active research work such as installing the Mayfly sensor suite. Teachers as experts (role 6) also emerged in academic year codes. Scientists, meanwhile, only occupied workshop leader and teacher mentor (roles 2 and 5) during summer institutes, but also became a classroom visitor/resource (role 3) during the academic years. The QRC team members served as co-developers of curriculum and negotiator/workshop leaders (roles 1 and 2) across all professional learning sessions, but also engaged as a research participant (role 5) during summer institutes and as a negotiator (role 4) during the academic year meetings.

Interview data frequency code counts illuminated an additional interesting discrepancy between stakeholder groups and how they discussed—implicitly or explicitly—their own and others' roles in the project, particularly around role 6 (teacher as expert; scientist as learner). Teachers were tagged as experts a total of 52 times, with all but two of these instances drawn from scientist or QRC leadership team interviews; thus 96% of all role 6 references were made by scientists (61.5%) or by the QRC leadership team (34.6%). By contrast, only one teacher (and only in a single excerpt) discussed themself as an expert and scientists as learners.

4 | DISCUSSION

Successful collaboration was accomplished by the QRC leadership team negotiation practices, by creating equitable participation space, and by leveraging stakeholders' expertise.

4.1 | Negotiation practices were key for bridging stakeholders' research and pedagogy

To bridge the gap between school and research contexts, QRC leadership team negotiations centered on teachers' requests and how to effectively elicit accessible information from scientists during collaborative meetings. We intentionally adopted this approach to address concerns raised in previous studies about scientific research findings being too complex to comprehend or relate to for students (Bopardikar et al., 2023). Leveraging the graduate student presentations as a model for scientists in preparing their materials for teachers proved highly effective and provided clear guidelines for presentation timelines and using accessible language.

Much of the QRC team's negotiation efforts occurred "behind the scenes," through ongoing discussions with stakeholders between professional learning meetings to connect scientists and teachers in meaningful ways. This negotiation work included the logistical aspects of navigating stakeholder expertise while still accomplishing professional learning goals. Coupled with our collective expertise from previous research–practice partnership work, these efforts culminated in the development of the dataset website. Ongoing reflection on exit slips and teacher feedback fostered a shared understanding of "messy data" and "authentic research," making the website a valuable tool for teachers and scientists to share their work.

Previous studies have pointed to the importance of incorporating authentic data in K-12 classrooms (e.g., Gould et al., 2014; Schultheis & Kjelvik, 2020), while still acknowledging the barriers that can prohibit teachers from readily doing so. Critically, QRC team leaders dedicated time in the negotiation phase to simultaneously solicit data needs from teachers while discussing with scientists the possibilities for fulfilling those needs with authentic datasets. Teachers articulated the desire to incorporate data into their lessons, but were unsure about what was available, relevant, or readily understandable for their students. Forest scientists had deep knowledge of a variety of datasets but were unable to identify what kinds or formats would be helpful for the teachers. In response, the QRC team strategically structured professional learning sessions to engage scientists and teachers in dialogue around those needs and break down disciplinary and power barriers. The resulting learning experiences navigated the complexity of authentic research while making it relatable to students (Bopardikar et al., 2023).

4.2 | Equitable participation spaces in collaborative work should be intentionally created

Building communities of practice among rural science teachers is an important aspect of professional learning programs for equitable participation, allowing teachers to share ideas, improve their pedagogical approaches, and ultimately create more equitable STEM learning opportunities between urban and rural schools (Saw & Agger, 2021; Wingert et al., 2022; Zinger et al., 2020). Highly motivated stakeholders certainly helped our project succeed. Teachers wanted to be part of a community of practice integrating forestry research into their classrooms, and most scientists demonstrated a genuine passion for education and were eager to share their authentic research. The QRC team intentionally implemented a "Let's figure it out together!" approach to level the playing field between education researchers, scientists, and teachers, thus fostering an environment of equitable participation and trust. As a result, stakeholders built strong relationships while creating strategies for implementing authentic research in middle and high school classrooms.

Creating strong ties between teachers and scientists has demonstrated benefits in other collaborative studies (e.g., Aristeidou et al., 2023; Dresner & Worley, 2006; MacFadden et al., 2022); in our work, multiple stakeholders cited the community of practice as a key benefit. Teachers cited not only networking with forest scientists as beneficial to their curriculum work, but also indicated working within their working groups and with the education researchers as valuable to tackle implementation barriers that they might not have felt empowered to address alone. Finding ways to build such communities is particularly important for rural teachers to ensure equitable access to quality professional learning and authentic science learning for their students. In our work, monthly virtual meetings throughout the school year and planning summer institutes well in advance for maximum attendance were critical to community- and relationship-building, especially given the wide geographic range of participants.

4.3 | Emphasizing teacher expertise during collaborations can benefit all stakeholders

Building upon the Drayton and Falk (2006) framework, we propose including explicit roles for teachers and education researchers (see Table 2). As mentioned by Farrell et al. (2019), if stakeholders do not have shared understandings of their roles, collaborative partnership efforts can stall. Articulating roles can help the team as a whole identify if they are meeting key RPP indicators, such as disrupting problematic power dynamics (1E) and ensuring all stakeholders are engaging from a learning stance (3D, 5A). In this project, the QRC leadership team did have an awareness of the roles they played as negotiators between scientists and teachers in many of the professional learning spaces. Additionally, the leadership team had some explicit discussions with scientists prior to professional learning sessions about occupying specific roles (e.g., encouraging scientists to occupy role 5 during the Mayfly sensor installation to foster true collaboration in decision-making). However, explicit conversations about these roles were not a regular practice, particularly with respect to the roles teachers played, perhaps contributing to teachers' downplaying of their own expertise. Future work could therefore benefit from these roles being more explicitly discussed as a group.

We also offer an additional set of roles to the Drayton and Falk (2006) framework in which teachers are positioned as the experts and scientists as the learners (role 6). Previous studies investigating scientist–teacher interactions typically describe translating authentic scientific content and practices into K-12 teaching (e.g., Atias et al., 2023; Brown et al., 2014; Morrison, 2014), largely limiting the impacts of teachers' pedagogical expertise to their own classrooms and ignoring potential broader impacts on scientists and their work. Our results indicate that scientists deeply value teachers' expertise, even when teachers do not view themselves as experts. Our new proposed role 6 may help teachers develop this mindset, allowing them to view themselves as experts in RPPs. Disrupting the conventional positioning of scientists as experts and teachers as learners can also impact scientists' professional domains beyond collaboration settings, such as how teachers' questions about cold pooling resulted in deeper reflection and potential new lines of inquiry for Anna, the Advanced Sensing scientist. Few studies have acknowledged such instances of building scientist's knowledge beyond the context of collaborative spaces. Caton et al. (2000) briefly mention that scientists involved in the teacher professional development of their study "reflected on their own teaching as a result of their collaborations with participating teachers," noting that "...these partnerships may be an exciting way for precollege teachers to influence science instruction in colleges and universities" (p. 14). Atias et al. (2023) also acknowledge that schools can play an important role in scientific research, particularly within the context of citizen science initiatives. We recommend that similar projects aiming to involve teachers and scientists in partnership work not only consider best practices from the research–practice partnership literature (e.g., Henrick et al., 2023; Warwick et al., 2020), but also ways in which teacher expertise can be leveraged beyond the traditional "classroom feasibility" lens to ensure learning between stakeholders is truly a two-way street.

5 | CONCLUSION

Our research findings point to several important strategies to inform future collaborations between scientists and teachers. First, STEM education researchers (the QRC leadership team in this case) can serve a key negotiation role in connecting the needs and expertise across teacher and scientist stakeholders to strengthen project work overall. Second, the iterative development of the data website was a first step to bridging theory and practice in engaging students with messy data. Finally, we found that creating spaces for teachers to take on expert roles while showcasing their knowledge to scientists had far-ranging impacts beyond the lessons developed for this project, as scientists incorporated this expertise into their own teaching and research.

Limitations to this study include drawing upon our own research meeting notes as a data source, which may be influenced by the research team's personal perspectives and preferences in approaching partnership work. Interview questions also did not probe teachers' previous professional learning experiences to provide a comparison to our approach. Moreover, we did not include RPP-related questions in early interviews to document the progression of teachers' perceptions regarding the project's collaborative approach throughout their participation. Although our original intention was to better understand the impacts of the learning experiences designed by teachers through classroom observations, the COVID-19 pandemic prohibited these visits. Despite these limitations, all stakeholders expressed gaining benefits through their participation in this work.

Several questions remain that offer ways in which to expand upon our collaborative work. First, while broad networks were employed to recruit teachers for this project, how might future efforts reach teachers who do not self-select for projects like this? How do we continue to explore ways in which rural communities and school districts can foster meaningful connections with scientists' academic and research expertise? Additionally, expanding upon the roles framework (Drayton & Falk, 2006) to include roles for students may provide avenues for assessing student learning in similar collaborations. Future collaborative partnerships seeking to bring authentic research to K-12 instruction should also consider ways in which current scientific research can be leveraged for learning while making data accessible for classroom use. Climate change research may therefore be a compelling and relevant driver for more partnership work in the future, as it offers scientists and teachers a growing body of messy and relevant data to bring into the classroom for authentic inquiry opportunities.

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CONFLICT OF INTEREST STATEMENT

I have no known conflict of interest to disclose.

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