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Leading instructional improvement in elementary science: State science coordinators' sense-making about the Next Generation Science Standards

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Abstract

The Next Generation Science Standards (NGSS), a reform effort "for states, by states," advances ambitious ideals for elementary science teaching, but the fate of these ideals will depend in part on the engagement of state science coordinators (SSCs). This article explores the responses of SSCs to NGSS in a purposeful sample of 18 US states. Based on analysis of 19 interviews with 22 SSCs, we develop two arguments. First, SSCs' ideas about improving elementary science education converged around three themes: the introduction of three-dimensional science teaching and learning, the integration of engineering with science teaching, and the integration of science with ELA and mathematics. Second, SSCs' sense-making about reforming elementary science education was situated in and shaped by (a) their knowledge of how elementary science instruction has been and continues to be de-prioritized, as well as their experiences (b) facilitating work groups in developing science standards using the *Framework for K-12 Science Education*, and (c) participating in professional networks.

KEYWORDS
elementary, reform, standards, state coordinators

1 | INTRODUCTION

Over several decades, federal policy makers and school reformers in the United States have focused their attention on classroom teaching and learning, specifying what teachers should teach, how they should teach, and defining acceptable levels of student achievement. With respect to elementary education, most federal reform efforts have centered on English language arts (ELA) and mathematics (e.g., No Child Left Behind Act, Common Core State Standards). Federal educational policies, particularly those attached to accountability measures, influence what teachers teach—thereby marginalizing low-stakes subjects, diverting resources to students more likely to pass the test, and increasing teaching for test-taking skills (Darling-Hammond, 2004; National Academies of Sciences, Engineering, and Mathematics [NASEM], 2009; Valenzuela, 2004).

Still, ELA and mathematics on their own do not constitute an elementary education. We also expect that children will learn about social studies, science, art, music, health, and physical education. We can potentially learn much from efforts to reform other elementary school subjects that have not figured as prominently in federal legislation nor in the empirical literature.

Elementary science offers an interesting case for three reasons. First, as noted above, science is largely ignored in US federal efforts to improve elementary schools. Second, elementary science has also been sidelined, and increasingly so, by US school systems and practitioners (Smith, 2020). As such, efforts to transform elementary science face a unique challenge compared with ELA and mathematics because advocates must justify why it is important to teach given competing school subject demands. Third, though elementary science has largely been minimized in US federal and state policy efforts for decades, there have been *national* efforts to reform the quality of elementary science education dating back to the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1994).[1]

1.1 | Current elementary science education reform context

In this article, we focus on recent national efforts in the United States to reform elementary science education—the *Framework for K-12 Science Education* (hereon referred to as *Framework*; National Research Council, 2012) and its companion Next Generation Science Standards (NGSS Lead States, 2013). Specifically, we examine how states are responding to this national elementary science education reform effort. The *Framework* outlines an ambitious vision for science instruction focused on learning scientific content through engagement in science practices with attention paid to concepts that cut across scientific disciplines. The NGSS reflect a new iteration of standards-based reform seeking to improve instruction through adoption of ambitious standards in the content-areas. Emerging as a national policy movement with voluntary, state-by-state alignment to the standards, the NGSS are presented as a reform initiative "for states, by states" (NGSS Lead States, 2013). In this way, the NGSS, with the accompanying *Framework* document, are intended to function more as guidance, rather than a mandated blueprint, for effecting change in science instruction (Schwarz et al., 2017). Further, the NGSS have maintained the status of a national movement with active involvement from outside of and within state governments allowing it to dissociate from federal and state politics that complicated the rollout and implementation of the Common Core State Standards for mathematics and ELA in many states (McDonnell & Weatherford, 2016).

This article explores (a) how states are (or are not) engaging with national efforts to reform science education and (b) how state-level science coordinators have come to make sense of these efforts. We develop and support two main claims based on our data analysis: First, we argue that state science coordinators' (SSCs') understandings of science education reform converged around three core themes: three-dimensional (3D) science teaching, the integration of engineering with science, and the integration of science with literacy and mathematics. Second, we argue that SSCs' sense-making was situated in three key ways: the ongoing de-prioritization of elementary science, the collective development of state standards with the *Framework* as a guiding document, and their engagement with national professional networks.

2 | THEORETICAL FRAMEWORK

We use intergovernmental relations and policy implementation literatures to situate and motivate our work. Additionally, we use sense-making literature on policy implementation to frame our analysis.

2.1 | Instructional reform and intergovernmental relations

Fundamentally transforming classroom instruction is not easy (Coburn et al., 2012; Cohen, 2011; Kennedy, 2005). Research suggests that all but a small number of unusually capable teachers will need considerable support in transforming instruction to support new learning ideals such as those of the NGSS (Benedict-Chambers, 2016; Blumenfeld et al., 2000; Cohen & Ball, 2007; Cohen & Hill, 2001; Davis & Haverly, 2022; Duke, 2000), and all but a small number of unusually capable schools will need support from their school districts and state in developing capabilities to support teachers (Spillane et al., 2016, 2018). Hence, one challenge facing national reformers involves engaging state and local governments to incentivize and support school leaders and teachers in transforming elementary science education.

Arrangements for governing instruction and interorganizational arrangements that structure principal–agent relations (such as state departments of education and school districts) complicate instructional improvement (Gauld, 2018). Responsibility for instructional policymaking is not clearly demarcated or defined in the branches and levels of government that exercise policy jurisdiction in the US federal system. The segmented policy system sends a mélange of mixed and often competing signals that can undermine the authority and power of policy (Cohen & Spillane, 1992; Floden et al., 1988). These arrangements complicate relations between policy/reform initiatives at the national, state, and local levels, in addition to school and classroom practice because it is often unclear which policy signals implementing agents should attend to and to whom they are accountable for implementation.

The construct of "loose coupling" from organizational theory describes the disconnect between formal government and classroom instruction (Bidwell, 1965; Meyer & Rowan, 1978; Weick, 1976). Loose coupling has roots in the complex environments of US public education, where authority and influence over schools is distributed within and among levels of government, professional associations and organizations, and non-profit and for-profit organizations (Cohen & Spillane, 1992; Rowan, 2002; Smith & O'Day, 1991). Fragmented educational environments have long provided systems and schools with uncoordinated and turbulent agendas, resources, and expectations, often absent much guidance for changing day-to-day instructional or leadership practice. This disconnect is the challenge to be addressed in bridging from the NGSS to classroom instruction. If the national movement to improve science instruction is to shape the elementary classroom, engaging actors at the state and local government levels and in the vast extra-system will be critical. From the perspective of the NGSS, the challenge is that this historical legacy of loose coupling *persists*, even as national reformers engage in efforts to fundamentally transform instruction (Peurach et al., 2018; Yurkofsky, 2017).

State-level actors can play an important role in supporting and sustaining the NGSS. In the standards-based reform era, state departments of education have come to play a larger role in reform efforts (Herrington & Fowler, 2003; Timar, 1997; Weiss & McGuinn, 2017). No longer functioning as agencies focused only on compliance with federal regulation and dictating use of funds (Weiss & McGuinn, 2017), some state educational agencies are now more actively serving as "architects and implementers of key policies" (Aspen Institute, 2015, p. 1) and have more latitude in determining educational agendas (Weiss & McGuinn, 2017). Absent federal policy incentives, state level actors will be especially important for the success of the NGSS. Yet, despite the increased role of state educational agencies in supporting student success, research on the institutional role of these agencies is sparse (Brown et al., 2011; Timar, 1997), as is research on the sense-making of state-level actors. In this article, we examine how state science coordinators engage with and make sense of efforts to reform elementary science education.

State-level actors, as well as actors at other levels, can exercise autonomy and demonstrate unwillingness and limited capacity to change their behavior, thus creating a disconnect between policy and practice, complicating federal and national efforts to transform instruction (Berman & McLaughlin, 1978; Hjern, 1982; Lipsky, 1978; McLaughlin, 1987). State, local, and school level implementing agents may also fail to notice, intentionally ignore, or selectively attend to policies that are inconsistent with their own (and/or their agency's) interests and agendas (Firestone, 1989). Policies that fit their agendas are more likely to be implemented, and those that do not are more likely to face resistance or get modified to make them fit. A tension for the science education reform effort, then, may be how closely aligned the vision of the *Framework* is with the agendas and interests of policy makers and, in particular, with state-level actors that lead and support the improvement of elementary science.

Another more recent explanation of the disconnect between policy and practice centers on implementing agents (at the state, local, or school levels) misunderstanding the ideas advanced by policy and reform (Spillane, 2009; Spillane et al., 2002). Thus, the sense-making of the agents who are implementing the reform provides numerous opportunities, aside from any intentional efforts to revise policy, for the transformation of instructional reform ideas. To understand the implementation of the NGSS, we must explore the mechanisms by which implementing agents, in this case, SSCs, understand policy and attempt to connect understanding with practice. We adopt a sense-making perspective on implementation to frame our work.

2.2 | Sense-making and implementation

A sense-making perspective begins by examining what people are noticing in their environment—how they author their environment (Weick, 1996). Sense-making is triggered when automatic processing is interrupted and people are prompted to notice puzzling cues and reconstruct their understanding of the novel situation (Louis, 1980; Louis & Sutton, 1991). Situations involving ambiguities, contrasts, discrepancies, uncertainties, and surprises can trigger sense-making. For example, conflicting goals or limited available resources to accomplish a goal can be sources of tension that trigger sense-making (Weick, 1995). These situations arise when policymakers and practitioners encounter instructional reforms that challenge their extant beliefs and practices (Coburn, 2004, 2006; Spillane, 2009; Spillane et al., 2002; Spillane & Callahan, 2000). Policymakers and practitioners engage in sense-making in an effort to coherently connect or transform their ideas and understandings with the new ideas advanced by policies and reforms.

Additionally, from a sense-making perspective, state educational organizations exercise agency in responding to their environments including national reform initiatives. These organizations "enact," or author, their environments rather than those environments directly communicating, disseminating, or transferring unequivocal information and knowledge into the organizations they seek to assert influence on (Pfeffer & Salancik, 1978; Weick, 1979).

One way that individuals within organizations "enact" the environment is through their noticing and use of resources. As individuals engage in sense-making, they draw on personal, material, and social or environmental resources (Allen & Heredia, 2021; Ball & Cohen, 1999; Cohen et al., 2003). Personal resources include one's beliefs, skills, motivations, and knowledge. Material resources include artifacts, curricula, policy documents, and time. Social or environmental resources include policies, leaders and their agendas, discourse communities, and the "actual, imagined, or implied presence of others" (Allen & Penuel, 2015, p. 137).

As suggested by the presence of social resources, sense-making is a social process. Individuals engage in sense-making with others, in professional learning communities or other discourse-rich environments (Allen & Heredia, 2021; Ball & Cohen, 1999), leveraging sets of resources as they do so. As such, individuals' sense-making may be influenced by participants' own or others' ideologies, norms, and worldviews (Allen & Penuel, 2015).

Within the field of science education, sense-making is more often invoked when describing children's sense-making of scientific phenomena (Odden & Russ, 2018; see also, e.g., Haverly et al., 2018; Warren et al., 2001). More recently, some science education researchers are beginning to consider the role of sense-making in teachers' and leaders' learning (Allen & Heredia, 2021; Allen & Penuel, 2015; Davis et al., 2020; Heredia, 2020; Marshall et al., 2021; see Spillane & Callahan, 2000, for an early example). Much of this scholarship considers the roles of coherence and incoherence between the ideals of reforms in relation to teachers' and leaders' environments, their beliefs, and their prior practices. For example, Heredia (2020) found that over a 3-year professional development (PD) experience, from year to year, participating teachers' environments changed, introducing new sources of incoherence each year between PD goals and school policies (e.g., new pacing guides, new teacher evaluations). Each source of incoherence shaped teachers' ongoing sense-making about the PD and their broader environments.

To our knowledge, this sense-making framework has yet to be used to analyze what state-level coordinators understand about science reforms or how they come to those understandings. Thus, our study builds on this established literature by analyzing the sense-making of SSCs in response to the reform initiatives introduced by the *Framework* and the NGSS that advance ambitious and novel ideas for reforming science education. These documents are likely to challenge policymakers' and practitioners' beliefs and practices in ways that promote their sense-making around the reform ideas.

Central to the *Framework* and the NGSS are five key innovations for science education: 3D learning; coherent learning progressions; engagement with phenomena and design solutions; science and engineering integration; and science connections to mathematics and literacy (Next Generation Science Standards, n.d.). These learning ideals of the *Framework* and NGSS are not meant to promote incremental improvement but, instead, to motivate transformative change in how science is learned in schools, including in elementary schools. For example, they imply a need to frame academic content not as the presentation-and-representation of established scientific facts but, instead, as interdependent theories, models, and practices for students to enact, figure out, and explain. Further, they imply a need to conceptualize academic tasks and assessments not as a test of rote memorization of established facts but, instead, as active engagement that requires demonstration of scientific thinking, reasoning, and skills. Finally, they imply a role for students as agents of their own learning and a complex role for teachers in designing, organizing, and supporting such learning among diverse students with varying backgrounds, motivations, and interests. For this reason, we consider working toward equity an additional ideal that the *Framework* promotes. Taken together, these innovations and ideals suggest a dramatic shift in elementary science education that is likely to trigger sense-making among implementing agents at all levels.

To summarize, we see SSCs as a linchpin between national reform efforts, districts, and schools. SSCs play active roles in national efforts, and they make decisions about what to bring in and keep out of their states. Therefore, how SSCs understand and take up national reform efforts has implications for schools. We might expect that political or historicized conflicts could arise for SSCs as they engage in this work; looking for such conflicts is one goal of this study.

Our analysis centers on how SSCs are making sense of national efforts to transform elementary science education in their work. Our research questions are:

1. How do SSCs understand the elementary science reform ideas set forth in the *Framework* and NGSS?
2. How is SSCs' sense-making about reforming science education situated and shaped?

3 | METHODOLOGY

This study is part of a 5-year National Science Foundation-funded project exploring the work of developing coordinated school-level and system-level elementary science learning environments to actualize the *Framework* and the NGSS. In this article we use data collected in the first year of the project.

3.1 | Sample selection

We used a qualitative, cross-case design of 18 states to explore state-level policy and practice around elementary science. We sampled states that varied on the following dimensions.

- Type of science standards: including states (a) that adopted the NGSS ("NGSS-adopted"), (b) with science standards based on the *Framework* and/or NGSS ("*Framework*-based"), and (c) in the process of revising standards based on the *Framework* ("in process").
- Reputation for reforming elementary science. Using a snowball sampling method, we gathered recommendations and input from 62 experts and leaders in US elementary science reform to identify leading states and individuals working in this area. We sampled across numbers of recommendations.

- States that were and were not NGSS Lead State partners (Lead States were involved in the drafting of the NGSS; their states' adoption processes varied after the completion of the NGSS). We hypothesized that involvement as a Lead State may impact SSCs' sense-making about the NGSS/*Framework* in particular ways.
- Size/population, geographic location, and political leaning.

States are identified by pseudonyms according to three characteristics: Region, State Standards, and Participation as NGSS Lead State (see Table 1). For example, *S Frame Lead* refers to a state in the South or Southwest with Framework-based standards that served as a Lead State.[2]

3.2 | Data collection

We conducted 19, 60-min, virtual, semistructured interviews with 22 state science coordinators in 18 state departments of education. In three states, we interviewed more than one SSC at a time, and in one state, we interviewed two SSCs separately. For simplicity, we report data by state rather than by participant. The interview protocol was designed to learn about each state's elementary science reforms, in part to inform our decisions about which states to select as case studies for the broader project. We asked questions on (1) their roles, responsibilities, and backgrounds; (2) their policy context; (3) the differences between previous science education policies and current ones; (4) their current priorities and visions for elementary science instruction; (5) their plans for supporting elementary science reform; and (6) the challenges they were experiencing in this work. SSCs' sense-making emerged from our questions. We also collected a range of publicly available documents including state science standards, curricular resources, and implementation guidance or tools.

3.3 | Analysis

We began analysis by reviewing recent publications on science education reform (Achieve, 2017a, 2017b, 2019; Committee on STEM Education, 2018; NSTA, 2018) to establish a set of provisional codes that described policy environments for elementary science education (Saldaña, 2016). Using NVivo 12 Pro (QSR International Pty Ltd, 2018), a qualitative data analysis software, the first two authors piloted the provisional codes and open coded two interview transcripts. Additional codes and subcodes surfaced in the data including one related to SSCs' instructional vision for elementary science that became central to addressing our first research question. We discussed our interpretations of the data and codes to work toward greater coding reliability. As we coded the remainder of the transcripts, we continued meeting to discuss the codes, revising as needed based on what surfaced in the open-coding process. See Table 2 for samples from our codebook (the full codebook is available from the first author).

Through ongoing conversations about the data and analytic memo writing (Emerson et al., 1995), we began to construct answers to the research questions. For our first research question, we identified themes from the data emerging from the instructional vision code, and we created sub-codes for those themes. For example, 3D science teaching emerged as a central theme and was assigned a sub-code. Next, we searched for related key words across the data. In the example of 3D teaching, we searched for references to science and engineering practices, disciplinary core ideas, and crosscutting concepts. We also sought references to specific

TABLE 1 State participants

Code	Geographic region	Type of science standards	NGSS Lead state	Number of Rec's	Political leaning
E Frame Lead	Northeast/Mid-Atlantic	Framework-based	Lead	High	Democrat
E Frame NL	Northeast/Mid-Atlantic	Framework-based	Not lead	Low	Democrat
E NGSS Lead 1	Northeast/Mid-Atlantic	NGSS adopted	Lead	Low	Purple
E NGSS Lead 2	Northeast/Mid-Atlantic	NGSS adopted	Lead	Middle	Democrat
E Process NL	Northeast/Mid-Atlantic	In process	Not lead	Low	Purple
MW Frame Lead	Midwest/Plains	Framework-based	Lead	Low	Democrat
MW Frame NL 1	Midwest/Plains	Framework-based	Not lead	Low	Purple
MW Frame NL 2	Midwest/Plains	Framework-based	Not lead	Middle	Purple
MW Frame NL 3	Midwest/Plains	Framework-based	Not lead	Low	Republican
MW NGSS Lead	Midwest/Plains	NGSS adopted	Lead	High	Democrat
S Frame Lead	South/Southwest	Framework-based	Lead	Low	Purple
S Frame NL 1	South/Southwest	Framework-based	Not lead	High	Republican
S Frame NL 2	South/Southwest	Framework-based	Not lead	High	Republican
S NGSS Lead 1	South/Southwest	NGSS adopted	Lead	Middle	Republican
S NGSS Lead 2	South/Southwest	NGSS adopted	Lead	Middle	Purple
S Process NL	South/Southwest	In process	Not lead	Low	Republican
W NGSS Lead 1	West/Northwest	NGSS adopted	Lead	High	Democrat
W NGSS Lead 2	West/Northwest	NGSS adopted	Lead	High	Democrat

examples of these dimensions (e.g., asking questions as a science practice). Finally, we exported references to these sub-codes into Excel spreadsheets to gain a deeper understanding of *how* SSCs were referencing these themes.

For our second research question, as we searched for evidence of SSCs' sense-making, we followed a similar process as described above as we assigned sub-codes to emergent themes. We found evidence of sources of tension that appeared to trigger sense-making, as well as collaborative processes, tools, and other resources that SSCs leveraged in their sense-making. For example, when SSCs referenced their standards adoption processes, we coded for instances SSCs referenced resources they leveraged for sense-making (i.e., through collaboration with others, engaging with the *Framework for K-12 Science Education*, and so on). Once again, we used NVivo to export all the references to our sub-codes, placed them in Excel spreadsheets, and further analyzed the data to count frequencies and identify patterns.

TABLE 2 Sample of the coding framework for elementary science state policy contexts

Parent and child codes	Examples from interview transcripts
[P]*Provisional code* [E]*Emerging code*	
1. Standards and accountability[P]	
1b. Assessments aligned to the standards[P]	"It still is—in [our state], we assess grade four science, and we are still having an issue with science being taught only in that fourth grade, and not moving to the primary in order to get students, giving them those experiences so that they are truly—they can truly demonstrate their understanding of science by grade four" (S NGSS Lead 2).
2. Resources for implementation[P]	
2a. State-initiated collaborations with external partners[P]	"We bring some of the providers together, sort of an open invitation to talk about ways that they can support science education. This was especially helpful during the time that we were a Lead State for NGSS. We got a lot of input from them and started to share framework ideas. Now during this last year, we have started to bring some of those players together, higher ed people and informal ed people, to share those" (MW Frame Lead).
3. Elementary science instruction[P]	
3b. Advocates for interdisciplinary learning[P]	"I would love to see us help people to think more about how we integrate science and a variety of other content areas so that elementary school teachers can find it to be more manageable. The NGSS are relatively complicated. In the old days, it was like, memorize some facts, and you are good *[laughter]*, which wasn't great, but when the pendulum swung, it swung to multidimensional standards" (W NGSS Lead 1).
4. Professional learning opportunities[P]	
4c. Professional learning for SSCs supported by the state[E]	"Achieve Incorporated runs a 50-state base camp, and they host monthly webinars, and it is strictly a collection of state science, DOE people across the country. We all have these policy issues. We can share in all of those kinds of struggles and challenges privately, and Achieve works very hard, also, providing assessment support, formative assessment supports and tools, and now Achieve is really focusing in on some direct district support" (S NGSS Lead 1).
5. Context[E]	
5b. Local control[E]	"In [our state], we generally—because we are a locally-controlled state, we do not have any mandates. The only mandates we have is them taking the state assessments, and those are driven by the standards. Even the standards are technically optional, so we are trying to be really strategic about giving really good guidance documents—creating guidance documents that can support the standards, but then helps districts" (E Frame Lead).
6. Other[E]	
6b. Instructional vision for elementary science[E]	"For so long they sat on the side, they had a kit—they read the instructions and they did what the kit said to do. How's that authentically having students ask their own questions that can be explored? I mean all of that changes the structure of the classroom and how the teacher's engaging the students. Some of our skillful teachers have really used the practices as opportunities for all of the kids in the room" (W NGSS Lead 2).

3.4 | Limitations

We identify three limitations. One limitation is the singular interview conducted in each state (with one exception). We focused on interviewing across a larger number of states instead of interviewing more deeply within states to explore potential variation across states. A second limitation is that we have not yet triangulated our state-level data with data from districts and classrooms. A third potential limitation concerns the interview protocol itself. The protocol was not designed to uncover SSCs' sense-making or processes for sense-making. As a result, we may have missed some facets of SSCs' sense-making that might otherwise have been shared if this had been the driving motivation for the interviews. Further research to investigate SSCs' sense-making about instructional reforms is needed.

4 | FINDINGS

Based on our analysis, we develop and support two central claims—one about a convergence of state science coordinators' understandings of science education reform around three core themes and a second about three key ways that SSCs' sense-making around those reforms were situated and shaped.

4.1 | SSCs′ ideas about improving elementary science education

SSCs′ understandings of reforming elementary science education converged around three central themes from the *Framework* and NGSS. All but one SSC stressed the importance of 3D learning, many indicated that integrating science instruction with engineering was an important new development, and a majority also emphasized the importance of integrating literacy instruction with science. Most attended to more than one of these themes.

4.1.1 | 3D science instruction

Most SSCs ($N = 17$) mentioned the importance of 3D learning in their efforts to improve elementary science, echoing a central theme in the instructional shifts advanced in the *Framework* and NGSS. SSCs focused on two central ideas related to 3D learning: (a) the integration of science practices (and crosscutting concepts) with science content, and (b) that 3D learning involves a substantial shift in classroom roles for teachers and students.

Integrating science practices (and crosscutting concepts) with disciplinary core ideas
When describing 3D learning, there was some variability in SSCs' conceptualizations. About half described 3D learning as an integration of science practices and science content while the other half included the third dimension of crosscutting concepts. For example, one SSC shared:

> We want to see the kids mucking around the science, having them engaged in culturally relevant, local, engaging phenomena, or having them figure out how to solve a local, culturally relevant problem in their community. We'd like to see it

> localized and we'd like to see kids actually constructing arguments, gathering evidence, constructing more arguments, and revising their thinking (E NGSS Lead 2).

The process of "constructing arguments" paired with "gathering evidence" and "revising thinking" is how this SSC described 3D learning as the integration of science practices in classrooms. This kind of description of 3D learning as foregrounding the integration of practices was typical of about half of the SSCs in our data set.

The other half included the crosscutting concepts as part of their vision of 3D learning. For example, this SSC described connections across the disciplines of science:

> You see this more integrated model where students can actually connect their learning from different disciplines of science and to see those connections across a whole year of education versus, this is life science discipline, this is Earth and space science. The content is much more integrated in what it was previously (S Frame NL 1).

Accounts focusing on integrating crosscutting concepts into 3D learning in an effort to break down the siloed treatment of the science disciplines were typical of about half of the SSCs. As such, we characterize some SSCs' ideas about 3D learning as mainly limited to two-dimensional (2D) science learning rather than three, where science practices once taught decontextualized from content are now being integrated with science content. However, we characterized other SSCs' ideas about 3D learning as more aligned to the ideals presented in the *Framework* and NGSS.

3D instructional shifts

SSCs also highlighted two key instructional shifts for 3D learning: (a) students figuring out explanations for science phenomena and having choice in the science classroom and (b) teachers, consequently, giving up some control.

SSCs emphasized the importance of students doing the intellectual work in the elementary science classroom while engaging in 3D learning to explain phenomena.

> As you know, with three-dimensional instruction, the teacher is setting the stage with coming up with the phenomena and the investigative lessons that will follow to help students explain that phenomena, but the real work comes from the students being engaged in trying to explain that phenomena through their learning experiences and their investigations (S Frame Lead).

This SSC, for example, believed classroom science investigations should be done in the service of supporting students to give an account of what they observed.

Other SSCs described this shift as giving children choice over their own learning.

> I would like to see teachers actually letting students do investigations and let them think and ask their own questions. A lot of times, teachers think, especially in the early grades, that they need to step-by-step go through every single process with them and hold the students' hands, basically. I would like to see students have more choice in where their investigation's going, what type of investigation they're going to do, being able to create explanations based off of those (E Frame Lead).

In this example, the SSC referenced two science practices—students generating their own explanations and asking their own questions—to describe how children might have choice in their own learning. As described by the SSC, this type of instruction involves teachers moving away from step-by-step processes for inquiry to a more open-ended, student-focused approach.

SSCs identified a challenge for teachers is giving up control so that children have more choice and can explain phenomena. For example:

> For so long they sat on the side, they had a kit—they read the instructions and they did what the kit said to do. How's that authentically having students ask their own questions that can be explored? I mean all of that changes the structure of the classroom and how the teacher is engaging the students (W NGSS Lead 2).

This SSC went on to explain:

> Now some of these new instructional strategies were instead of a word wall, you have a question wall. Then the students will put patterns in the questions and they organize them. Then they make choices. This is really scary for teachers if you have that experience yourself and you're being told 'Oh, here's a great new strategy for you. Go forth and try it out, and see how it goes for you' (W NGSS Lead 2).

As described by this SSC, the needed instructional shifts for 3D science teaching can be daunting for teachers who are more familiar with conventional models of teaching.

To summarize, there was some convergence in what SSCs noticed about instructional reforms related to 3D learning. First, most SSCs included 3D learning as integral to their instructional vision for elementary science instruction. However, about half of them characterized 3D learning as an integration of science practices with content—as more 2D than 3D. This is not surprising given how new the naming of the crosscutting concepts are in science education, and how underdeveloped they are instructionally relative to the other two dimensions. Second, many SSCs understood 3D instruction as involving a shift toward students doing more of the intellectual work through explaining phenomena and having more choice and control. This envisioned shift in students' classroom roles necessitates a complementary shift in teachers' roles.

4.1.2 | Integration of science and engineering

Most SSCs ($N = 15$) referenced the integration of engineering with science as a key feature of the current reform efforts. However, unlike with other themes, there was considerable variation in how SSCs understood what was involved in integrating science and engineering. While some focused on how engineering was built into their state standards as either core content and/or a set of practices, others concentrated on descriptions of engineering instruction as localized, project-based, and/or design-based. Still others foregrounded STEM integration and the role of robotics programs in their states. Variation of this sort might be expected given the relative novelty of engineering in the NGSS.

Some SSCs described how engineering was built into their state standards. For example, one SSC described how they treat engineering as a discipline rather than a practice:

> We already previously had a lot of engineering standards, and we treat engineering as a discipline versus a practice—an application, and so, one of the things we did is we made engineering the fourth domain of science. We have earth science, life science, physical science, and tech-eng[ineering], so we have four domains of science in [our state] (E Frame Lead).

In contrast, another SSC described engineering as a set of practices in their upcoming state standards: "I'm assuming that we do get engineering practices embedded in there, and we are focusing some on crosscutting concepts. Already, our elementary standards are very focused on the doing of science" (S Process NL). The contrast between engineering as a discipline versus a practice is one example of the range in SSCs' descriptions of engineering integration.

Other SSCs focused more on what engineering integration would look like in the classroom. For example, as one SSC described shifts in what classroom instruction would need to look like, they described children as designing their own solutions to problems:

> That's a huge shift for teachers, to shift from you being the expert to helping your students become the experts. I don't think that a lot of teachers trust that their students will pose the right questions ...If we can shift those mindsets in our teachers, then I think that they will be taken aback by the questions that students will pose, and the engineering design solutions that students will develop when they are utilizing the curriculum (S Frame NL 1).

Another SSC unpacked this notion of students designing solutions by describing the types of problems students might be addressing. They described students solving "a problem that is relatable to them. Or their community. You know, something they would care about" (MW Frame NL 1). Though only one SSC completely articulated this vision of engineering integration as students designing their own solutions to locally relevant phenomena in partnership with local industries, several others articulated portions of this vision.

A third way that SSCs referenced engineering integration was through articulating a vision for STEM integration.

> We're the home of—the world's home for biotech, biopharma. We're the world home for a lot of technology development. ... [W]e have large agriculture, and agriculture's now moving into a high-tech world. There's a lot of driving forces why [our state] sees that we really need to go back to pre-K through 12 and have everyone work collaboratively to ensure that kids learn those objectives over time (W NGSS Lead 1).

For this state, STEM integration was critical for maintaining its status as a world leader in technology and engineering. In another state, the SSC described using the term "STEM" with intention to draw more awareness to the oft-overlooked T (technology) and E (engineering):

> We can introduce that STEM framework to a group of people, and within minutes their language starts to change, whether it's administrators or teachers. They might say things like, 'Oh my goodness, all I'm offering my students is lowercase E at best. That's not what I intended to do, but I didn't know that was happening'. That emphasis is starting to have people electively change the way they're thinking

> about STEM in elementary to really emphasize science on grade level (S Frame NL 2).

Finally, in one state, STEM integration was described as an initiative promoted by the state's STEM Ecosystems (https://stemecosystems.org/), recognizing variety in the emphases of each group: "Some have been more computer science, some have been more robotics, some have been dealing with science, so there's a variation in there, too" (E Process NL).

In sum, from engineering in standards, to engineering as solving locally relevant problems, to engineering as part of STEM integration, there was considerable variability in how SSCs made sense of elementary engineering integration. Nevertheless, most SSCs acknowledged engineering as an important consideration among elementary science reform efforts despite how little attention engineering education has received at the elementary level.

4.1.3 | Integration of science with literacy (and mathematics) instruction

A majority of interviewees ($N = 14$) discussed integrating science with literacy and mathematics. Although SSCs framed their sense-making about interdisciplinarity around mathematics and literacy, when talking about what it would look like instructionally, examples focused entirely on literacy.

Some SSCs suggested that simply reading or writing about science was not sufficient for integrating science with literacy, a common critique of interdisciplinary teaching. One SSC recognized that their efforts toward integration have "been misinterpreted as, 'I'm going to have my kids read a nonfiction text about car collisions, and that's going to be our science for the week'" (E NGSS Lead 2). Put another way, "It ain't a book you read" (E Process NL).

Much of the work involved in moving toward more rigorous integration is in the messaging of the initiative. For example:

> This idea of integration, but thoughtful integration is something that we're really pushing for. It's not just reading about science in ELA and calling that a science class. That's one strategy, but we need to work on the messaging around that. The other strategy is helping district leaders to really see that you don't need to do an hour-and-a-half—90 minutes of ELA, 90 minutes of math, and then there's no time left in the day for anything else. Opening the door to different ways to approach learning all the subjects. Our work with the principals has been trying to get them to think outside the box a little bit (E Frame Lead).

For this SSC, "learning all the subjects" together in an interdisciplinary manner not only requires re-thinking the 90-min blocks of ELA and math instruction, but it also requires a more careful approach to integration that is "not just reading about science."

4.1.4 | Summary of SSCs' ideas about reforms

Overall, our analysis suggests that SSCs coalesced in their vision of elementary science reform around three key themes: three- (or two-) dimensional science teaching and learning, the integration of science and engineering education, and the integration of science with ELA (and mathematics). Within these themes, we found some variability, as might be expected. For example, while some SSCs incorporated the crosscutting concepts into their characterization of 3D instruction, others did not. Additionally, SSCs framed engineering education from a variety of perspectives, including as a set of practices, as taught through project-based learning, or as an integral part of STEM education initiatives.

Some research shows how the implementation of instructional policies fail because people (mis)understand the new ideas about improving instruction in ways that fit with their extant instructional beliefs and practice (Spillane, 2009). Those responsible for implementing policy or supporting its implementation assimilate, rather than accommodate, new ideas about reforming teaching and learning as they strive "to make the unfamiliar, familiar" (Flavell, 1963, p. 50; Spillane et al., 2002). Our analysis suggests a more optimistic conclusion documenting considerable consensus around a handful of ambitious reform themes among SSCs in our study. We next explore "*the how*" of SSCs' sense-making about elementary science education reform.

4.2 | Processes for SSCs' sense-making

Despite limited mandates and incentives for states to adopt recent reforms set forth by the *Framework* and the NGSS, SSCs' ideas about elementary science aligned reasonably well with reformers' proposals. Based on our analysis, we develop and support three claims about SSCs' sense-making about elementary science reform: SSCs' sense-making was situated in and shaped by (1) conflicting goals around the relative importance of science in the elementary curriculum, (2) working with colleagues to develop and/or adopt science standards and the role of the *Framework* therein, and (3) participation in professional networks that afforded SSCs discourse-rich environments for collective sense-making with colleagues and researchers nationwide.

4.2.1 | Sense-making situated in a common challenge and conflicting goals

SSCs' sense-making about reforming elementary science—in particular, with regards to integrating elementary science with literacy and mathematics—was situated in and shaped by the challenge of science being overshadowed by literacy and mathematics in elementary classrooms. That elementary literacy and mathematics takes priority over science for instructional time is well documented (Banilower et al., 2018; Blank, 2013). Our data show how the goal of prioritizing ELA and mathematics conflicted with SSCs' goals to improve elementary science education and therefore shaped nine SSCs' sense-making about reforming elementary science instruction toward encouraging the integration of science with mathematics and ELA. SSCs' rationales for such integration assert that science provides an interesting, authentic, and relevant context for mathematics and reading that increases students' disciplinary literacy, in turn improving student achievement in ELA and mathematics. Some SSCs used this integration argument to try to get science on the elementary agenda. These sense-making efforts focused on reducing the conflict by aligning the goals of science education more closely with those of ELA and mathematics.

Several SSCs noted that advocating for interdisciplinary learning is a way of getting science on the agenda of policy-makers—a way to increase science instructional time in elementary classrooms. For example, one SSC argued that elementary science provides students with an authentic context to engage in ELA and mathematics. This SSC reported using this argument to get science in front of policymakers in the first place. The SSC described that in their state's current framework for improving schools, districts struggle to attract and retain teachers and improve their test scores, and the SSC's response is, "well, have you tried problem-, project-, or place-based education?" (MW NGSS Lead). In other words, this SSC leveraged the state's own framework to make the argument that science instruction (specifically characterized as problem-, project-, or place-based) can provide an authentic context for teaching the other subject areas with the potential to make a significant difference in school improvement plans. This is an example of the SSC authoring their environment through sense-making.

Other SSCs also talked about how using science as a context for learning mathematics and ELA increases student achievement in these subject areas. For example, one SSC said:

> We know there's research out there that says if you're going to—that one of the things that helps students read and do mathematics is to do them in context, and that's where science and social studies and other areas help. It would behoove us to help students learn to read and do mathematics in the context of science or social studies or some other content area, as far as that goes, rather than in isolation. Once you get past the decoding and the basics, then being able to start, "Okay, let's move away from that and use it in context or begin to start using it in context" (S NGSS Lead 2).

Another SSC shared the following:

> We're, essentially, killing our students, and we're not seeing the change in student proficiency that we need to see by …essentially, boring our kids in school by forcing them to over-engage with ELA work separate from an authentic experience that gets them engaged and excited about reading about that, writing about that topic (MW NGSS Lead).

By leveraging an authentic science context for learning, these and other SSCs argue that students are more "engaged and excited" about ELA (and mathematics), and consequently, achievement can improve. These two SSCs are authoring their environments, situating their sense-making in managing a tension wherein elementary ELA and mathematics are prioritized over science.

Other SSCs offered disciplinary literacy as a rationale for interdisciplinary learning.

> The focus on math and ELA has been a focus for so long that it's really been difficult for teachers to shift their mindset and understand, "Hey. If you implement this quality curriculum that supports ELA and math through disciplinary literacy and by infusing Common Core throughout the program, that you are supporting your students in math and ELA, so you don't have to spend three hours on ELA or have a two-hour block for math, right? By implementing science, you're actually supporting that." That is a huge shift to get folks to really understand that your students are gonna get there if you focus on science (S Frame NL 1).

This SSC, for example, argued that by developing disciplinary literacy via science instruction, students' ELA and mathematics proficiency will improve. This marks a "huge shift" for educators who are accustomed to large blocks of mathematics and ELA time.

What SSCs noticed about integrating science with literacy and mathematics instruction was shaped by the limited time devoted to science instruction in elementary schools. The prioritization of elementary ELA and mathematics presented a conflict for SSCs that focused their attention on bringing the goals of elementary science closer to alignment with those of ELA and mathematics. While integration of ELA and mathematics with science features prominently in the NGSS, for SSCs, leveraging this interdisciplinarity also functions as a way to get science taught. In other words, as educators and legislators are laser-focused on improving elementary mathematics and ELA achievement, many SSCs are making a case for science education as a more effective means to work toward this end rather than requiring large blocks of stand-alone mathematics and ELA instructional time. This focus on integrating science with mathematics and ELA could be seen as constraining the ambitions of the reforms. Yet, it also reflects SSCs' understanding of the constraints within which they are working to reform elementary science. SSCs' sense-making was enabled by their ongoing processes of using the *Framework* to adopt or develop state science standards as well as in their participation in professional networks.

4.2.2 | Standards development and adoption processes as sites for sense-making

Sense-making is not an isolated event, but an ongoing social process. Situated in their efforts to develop the NGSS as a Lead State and/or adopt science standards for their states, 11 SSCs relied on both the *Framework* and opportunities to work with teams as they grappled with figuring out new reform ideas to press for improving elementary science. These standards development sites were discourse-rich environments in which SSCs drew on their own and others' ideologies, paradigms, and traditions in order to sense-make and reach decisions about science standards.

Many SSCs identified the *Framework* as critically important in their efforts to understand how to reform elementary science. One SSC, for example, noted:

> That period of time that we were reviewing and assisting in the writing [of the NGSS], people started really to wrap their head around the three dimensionality and how we could have the opportunity to really provide equitable learning for kids and equitable professional learning for teachers. We really dug into the appendices and chapter 11 [on equity and diversity] out of the *Framework*. I think everybody was carrying around the 'Cliff Notes' version in their pocket. We'd constantly be pulling these things out and really hammering in on our underserved populations of students, and we also brought the standards to kids (W NGSS Lead 2).

For this SSC, reviewing and writing the NGSS as a Lead State representative provided access to a community wherein they used the *Framework* to, among other things, collectively make sense of what it meant to support "underserved populations" in science education.

For states that were not Lead States, the *Framework* was also a valuable tool. For example, one SSC referred to a writing team for their state's standards adoption team ("workgroup A") and its engagement with the *Framework*:

> There's a desire to—and this really does come from the *Framework*. ... I've heard it from the State Board, I heard it from the content advisors, I heard it in

> workgroup A, to include engineering practices, which have not been part of our standards before. It's definitely from the *Framework* and NGSS. That's something very likely that we will see at the end of this (S Process NL).

In this example, stakeholders in the standards development process leveraged the *Framework* as a tool for figuring out how to integrate engineering practices with science. This led them to prioritize the addition of engineering into the state's standards. As in the previous example, this was accomplished in a discourse community with the aid of a material resource.

As captured above, many SSCs described a standards adoption or development process as involving work groups of multiple stakeholders. This process created discourse communities that fostered on-going sense-making. The stakeholders—including state-level leaders, teachers, parents, external support providers, university faculty, and other community members—had flexibility to make the standards their own, consistent with the NGSS philosophy of "for states, by states." SSCs described their involvement in work groups to write and review their state standards as important to their own and team members' sense-making. For example, one SSC reflected on the following questions that one of their work groups was grappling with:

> The second part that was super critical in the development of the standards was that the science standards work group members did a lot to look at the learning progression. Part of them looking at the learning progression, a lot of the discussions were centered around, Were the standards appropriate conceptually for students at different grade bands and different grade levels? Did they have the conceptual understanding as well as the skills from prior grade levels to be able to effectively understand the standards? Will teachers be able to effectively implement the standards based off of that? (S Frame NL 1).

For this state's work group, part of their sense-making centered on wrestling with learning progressions, a key theme in the *Framework*, and the discussions within this community figured prominently in this SSC's description of stakeholders' sense-making.

The process of developing either the NGSS as a Lead State and/or their own state science standards was important to SSCs' on-going sense-making about reform efforts including 3D science teaching, integrating science with engineering, and integrating science with mathematics and literacy. These ideas were influenced not only by the actual presence of others, but by the implied presence of those stakeholders who would be affected by them. In order to develop these science standards, SSCs facilitated and engaged in work groups with the *Framework*, thus engaging in collective sense-making through teamwork (a social resource) and using the *Framework* as a key material resource. However, these were not isolated state teams. They were connected to national and regional networks that provided sites for SSCs to share information and resources related to elementary science reforms. We turn to the role of these networks next.

4.2.3 | Professional networks as sites for sense-making

All of the SSCs in our study reported being involved in at least one, sometimes several, professional networks related to science education, and 14 SSCs described at least one of those networks as central to their sense-making around science education reforms. These networks included non-profit and for-profit organizations (i.e., corporate partners, Achieve, WestEd, and universities) and professional associations (i.e., Council of State Science Supervisors [CSSS] and the National Science Teachers Association [NSTA]). These networks (especially CSSS) were discourse-rich environments wherein SSCs discussed and negotiated what the NGSS meant for elementary science teaching and learning in two central ways: professional networks provided access to critical material and social resources in the forms of (a) information about elementary science education reforms and (b) resources and opportunities for collaboration.

Professional networks as providing access to information

Professional networks provided access to messages on core principles of elementary science reform and opportunities to explore, develop, and check their understanding of them. For example, one SSC described how they turn to professional networks to learn about the national agenda for science reform.

> As a state agency, our goals are really to think about what's going on nationally and what we can bring nationally to our districts, so we're part of the [Council for State Science Supervisors]. We're always learning what's going on. We stay in touch with NSTA and some of the bigger national organizations to bring that too (E Frame Lead).

Another SSC leaned on CSSS for assistance with sense-making around the *Framework* when challenges came up during their state standards development process.

> We had an engineer who was on us like crazy that, "NGSS said you must do engineering half the time, and half of your time must be spent on doing engineering practices. Half your time must be doing engineering content." I was able to reach out to CS Cubed [CSSS] and actually some of the writers of the *Framework* and say, "This is how I read the *Framework*. This is how he perceives it. Let me know if I'm wrong" … I wanted to make sure that I have the answer that best aligns to what national trends are and what was the intent in the *Framework*. They all reached back to me within two days. It was great (E Frame NL).

This SSC used the CSSS network to check their understanding of the NGSS—that is, that there is no expectation that engineering content make up half of science instructional time. This experience was triggered by uncertainty and conflicting ideas between the SSC and a vocal stakeholder, and drawing on the social resources available in the CSSS validated the SSC's understanding about the "intent in the *Framework*" and its instructional reforms.

For some SSCs, professional networks also helped broker relations that allowed access to and engagement with research, researchers, and research partnerships. For example:

> What I take from the organization [CSSS] is, one, it's a link to the Board on Science Education, Heidi Schweingruber's group [in the National Academies of Sciences, Engineering, and Medicine] when reports are being written. I've had the opportunity to be a reviewer and be on panels and learn a lot from that work. That's definitely because of the Council of State Science Supervisors (E NGSS Lead 2).

For this SSC, CSSS served as a broker for direct access to research, a critical material resource. CSSS also provided SSCs with access to research partnerships. For example, one SSC shared:

> They've also linked me with the ACESSE project out of University of Washington, University of Colorado at Boulder around—we're working on—it's a research in practice collaboratory, and we're looking at how to develop equitable systems to promote more equitable science learning opportunities for all kids (E NGSS Lead 2).

Membership in CSSS provided this SSC access to a partnership where they worked with leading researchers to support elementary science reform in their state. Keeping tabs with "national trends," validating interpretations of reform intentions, and working alongside researchers are examples of how SSCs' professional networks offered access to material and social resources that in turn helped them make sense of information about elementary science reform.

Professional networks as sites to develop and share material resources

For many SSCs, professional networks served as sites for co-designing resources around common challenges and sharing resources with colleagues. For example, one SSC stated:

> The other thing that I get from the organization [CSSS] is I can share the workload with other people. All of us that develop new materials to support teachers share it freely amongst the members, so that not everybody is developing a professional development tool that—if I wrote it, anybody can use it. That helps to reduce the workload a little bit.

The SSC went on to explain:

> It also gives me access to data much more quickly. For example, the other day I was asked what's the standard turnaround timetable for standards review and adoption. I was able to send an email to 200 of my closest friends. By the end of the day, I had a data table that suggested that the average time is between three years and ten years with seven years being the model (E NGSS Lead 2).

For this SSC, participation in CSSS created an exchange for material and social resources that helped reduce workloads and circulate ideas quickly. Another SSC also explained how professional networks serve as a conduit for sharing ideas. The SSC explained:

> We are experimenting and we're looking at doing some of the different styles of questioning on the standards assessment. I reached out to another science supervisor and said, "What do you know about this? I know you're doing that." She has given me feedback, some advice on that. I am the unofficial mentor to another science supervisor in [another state]. We just talk about, "what are your challenges, what are you doing with PD, what are obstacles you're facing, what are"—it's nice to have people to bounce ideas off of (E Frame NL).

For this SSC, CSSS provided a social resource in the form of discourse partners to problem solve common challenges members faced in supporting elementary science reform, in this case utilizing different question types on standards-based assessments. The relationships developed in the context of professional networks provided opportunities for information sharing and the co-construction of ideas as members collaborated around problems of practice in their work.

Variation in non-NGSS SSCs' engagement with CSSS

Two states in our study were in the process of updating their state science standards at the time of data collection and were leveraging the *Framework* in the process. As such, their current standards were not yet aligned to or informed by the NGSS. While the CSSS played a central role in many SSCs' sense-making around elementary science reform, there was variation in the perceived usefulness of this network for SSCs from these two non-NGSS states. One of the SSCs, for example, described feeling like an outsider in the network given that their state had not adopted the NGSS.

> I'm on that email list, and I do get to see those emails. Because we have not been an NGSS state or even adopted the *Framework*, we really have not engaged with them as a state very much. I have not been to their conferences. I haven't met them (S Process NL).

In contrast, the SSC from our other non-NGSS state described how connected they were to the network despite their state's adoption status, particularly for access to resources. They explained:

> In the late 90s when I started and ran a math/science institute where we provided professional development for districts, and how did the professional development providers receive their own professional development? There's very little out there. I rely on CS Cubed for a lot of resources. Although I'm not allowed to travel out of state to go to the conferences, I get a lot of the different things online from them that I can (E Process NL).

This suggests that membership in professional networks, particularly CSSS, did not have the same effect for all study participants.

To summarize, SSCs' engagement in professional networks, and especially in CSSS, created discourse-rich environments where SSCs reported interacting with one another around the reforms proposed in the *Framework for K-12 Science Education* and the Next Generation Science Standards. These networks facilitated SSCs' sense-making in two primary ways: by providing access to material resources in the form of information about elementary science education reforms, and by providing access to social resources in the form of colleagues to co-develop and share material resources with and to problem solve together.

4.2.4 | Summary of SSCs' sense-making processes

Our data analysis suggests that SSCs' sense-making about elementary science reform was situated in three primary experiences: the common challenge and conflicting goals related to the de-prioritization of elementary science instruction, the collective work in discourse-rich environments of developing the NGSS and/or state standards with use of the *Framework* as a key material resource, and participation in professional networks that served as additional discourse-rich environments that brought people together to engage in collective sense-making and to negotiate understandings of reforms. These shared experiences seem to have influenced consensus around key reform ideas as argued previously, despite those reforms being implemented without federal mandates or incentives.

5 | DISCUSSION AND CONCLUSION

Based on our analysis, we developed and supported two main assertions. First, state science coordinators' ideas about elementary science education improvement efforts converged around three themes: the introduction of 3D science teaching and learning, the integration of engineering with science teaching, and the integration of science with ELA and mathematics. Second, while SSCs' sense-making about reforming elementary science was situated in challenges and conflicting goals associated with the de-prioritization of elementary science instruction, it was also (a) grounded in facilitating work groups as discourse-rich environments to develop state science standards and/or the NGSS using the *Framework for K-12 Science Education*, a key material resource, and (b) embedded in professional networks offering material and social resources, including the Council of State Science Supervisors.

While SSCs appreciated the challenges in reforming elementary science education in their states, our analysis documents remarkable consensus among SSCs in their vision for elementary science instruction. We see this national movement for elementary science education reform as a state-by-state movement that gained traction without federal mandates, resulting in convergence in leaders' thinking around elementary science instruction.

5.1 | SSCs' ideas about elementary science education reform

SSCs converged on a few critical points regarding their vision for elementary science instruction including the importance of 3D science instruction, engineering integration, and the integration of ELA and/or mathematics with science in ways that move beyond reading informational texts. There are other key ideas from the reform documents that did not figure as prominently in SSCs' accounts, including leveraging learning progressions to build coherent learning opportunities for students over time, organizing science instruction around locally relevant phenomena, and promoting equity in science education reforms.

One possible explanation for these patterns is that SSCs' ideas about elementary science reflected their existing beliefs and ideas about science instruction with more familiar ideas getting attention, whereas novel ideas figured less prominently and/or were not yet fully developed. Constructing new ideas about reforming teaching from policy texts, educators' understandings tend to focus on the familiar, assimilating them into their understanding and practice (Coburn, 2004; Spillane, 1998). For example, though many SSCs spoke about the importance of 3D learning, for roughly half, their understanding of this idea was chiefly 2D, emphasizing the importance of integrating content with practices but neglecting the crosscutting concepts. Considering that inquiry skills (akin to science practices) have been a part of science standards since the release of the National Science Education Standards (National Research Council, 1996), and that curricular reforms going back to the 1960s emphasized process skills (Rudolph, 2019), these ideas are more likely to be familiar to SSCs. Yet, process skills have been listed separately in many states' science standards and often taught devoid of science content or context (Monhardt & Monhardt, 2006). The shift toward 3D learning with the

Framework merged practices and content standards in performance expectations. Thus, the primary shift for educators is to assure that these practices are taught *in the context or service of* the disciplinary core ideas, rather than as discrete skills taught devoid of context.

In contrast, the third dimension of crosscutting concepts is more novel. Instruction in the crosscutting concepts has been tacit with limited research on the matter (Fick & Arias, 2019; National Research Council, 2012; Nordine & Lee, 2021). As such, it is unsurprising that about half of the SSCs had yet to figure out how to articulate this part of their 3D instructional visions.

The same rationale can be applied with respect to the integration of engineering in SSCs' understandings about elementary science reform. With increasing attention paid to STEM (National Academy of Engineering and National Research Council, 2009), engineering has been on educators' radar for over a decade. Additionally, engineering standards, to varying degrees, were already included in many states' science/STEM standards (Carr et al., 2012; Moore et al., 2015). While many SSCs described integrating engineering with elementary science, they have yet to coalesce around a vision of what engineering integration might look like in elementary schools. More work is needed to develop a shared vision of engineering integration across states.

Finally, integrating science with mathematics and/or ELA, another idea prominent in SSCs' understandings about elementary science, resonates with long-standing philosophies of thematic instruction, project-based learning, and literacy integration, particularly in elementary classrooms (Anderson et al., 1997; Blumenfeld et al., 1991; Krajcik et al., 2021; Vitale & Romance, 2011), as well as newer calls for such integration (NASEM, 2021b). However, SSCs' descriptions of integrating science with ELA and mathematics focused heavily on literacy, not mathematics. This raises questions about why SSCs seem to prioritize integration with literacy over mathematics. One reason may be strategic. In response to increasing pressure across states to improve young students' literacy (e.g., Michigan's third grade reading law, Arkansas's science of reading law) many districts, school leaders, and teachers are placing even higher emphases on reading instruction and blocking out large chunks of time for ELA (Smith, 2020). Finding ways to effectively integrate science with ELA, more so than with mathematics, may be a strategic, even necessary move to get elementary science on educators' agendas.

Other ideas promoted by science education reformers were backgrounded in SSCs' ideas about reforming elementary science. For example, SSCs primarily brought up learning progressions in conversations about their states' science standards adoption processes, but not in relation to classroom instruction. Similarly, though several SSCs mentioned the importance of students investigating or explaining phenomena in classrooms, this was not a common theme among SSCs, perhaps because, as with the CCCs, phenomenon-based instruction is an underdeveloped idea in the *Framework*. Further, equity was not a central theme in SSCs' interpretation of the NGSS/*Framework*. Though nearly all SSCs addressed equity concerns, the vast majority focused chiefly on access and opportunities being available to all students across their states. Only a few described efforts to support the use of culturally relevant phenomena in science instruction. Finally, while included in the recent Call to Action report (NASEM, 2021a), the notion of increasing accountability measures for elementary science education, though acknowledged as a challenge, was not broadly offered as a solution.

5.2 | SSCs' sense-making

Though our analysis finds that not all of the core ideas outlined in the *Framework* and NGSS are central to SSCs' conceptualizations of elementary science education, the convergence around some key features of the *Framework* and NGSS suggests a level of consistency (and progress) in SSCs' visions of reform. In the absence of federally driven mandates and inducements, the national science education reform movement penetrated state policy-making, even in states that had not adopted the NGSS, converging around several key innovations. Such convergence and commitment to reforming elementary science education is even more remarkable considering that SSCs were well aware of the immense challenge they faced in getting school districts and schools to pay attention to elementary science education. Indeed, this was a central source of tension (Weick, 1995) that nearly every SSC mentioned: the conflicting goals between systems' and school leaders' prioritization of elementary ELA and mathematics, with SSCs' efforts to improve elementary science instruction. This tension triggered SSCs' sense-making for integrating science with literacy and mathematics, consistent with other literature that shows the importance of ambiguities and incoherencies in triggering sense-making (Allen & Heredia, 2021; Heredia, 2020; Spillane et al., 2002; Weick, 1995).

Our article highlights the importance of two key discourse-rich environments (Allen & Heredia, 2021) as sites for SSCs' sense-making: (a) standards writing or adoption processes and (b) professional networks, especially the CSSS. Within these environments, SSCs leveraged personal, material, and social resources for sense-making (Allen & Heredia, 2021; Allen & Penuel, 2015; Ball & Cohen, 1999; Cohen et al., 2003). While personal resources like SSCs' commitments to science education reform may have brought them into their roles and subsequently these discourse-rich environments, these sites in turn provided SSCs with valuable material and social resources for engaging in sense-making, allowing them to develop richer understandings of the reforms, and thus further developing their personal resources. The material and social resources within these sites offered multiple opportunities and entry points for SSCs to sense-make about 3D elementary science teaching, the integration of science and engineering in elementary classrooms, and the integration of science with literacy and mathematics teaching.

For example, three key material resources that surfaced in our analyses of SSCs' sense-making were the *Framework* itself, access to current research and information on interpreting and implementing the *Framework*, and access to one another's co-created *Framework*-aligned resources. These material resources shaped SSCs' sense-making within discourse-rich environments; were iteratively used in national- and state-level forums; and offered shared ideologies and paradigms for co-constructing meaning around the *Framework* and NGSS. That the *Framework* and corresponding material resources were so influential for SSCs suggests that they were largely within the range of SSCs' personal resources—that is, their skills, motivations, and knowledge—and SSCs could make use of them for their own and others' sense-making (Cohen et al., 2003). Engaging deeply with the *Framework* and the NGSS often occurred for SSCs as they constructed and defended state standards. Using the *Framework* in this way is consistent with prior research showing that the use of external material resources can shape the ways individuals come to understand policies (Hill, 2003; Spillane, 1998; Stein & Coburn, 2008) and how SSCs, in particular, carry out their roles and responsibilities (Hopkins, 2016; Hopkins & Gates, 2018). SSCs referred to the importance of the *Framework* whether their state adopted or adapted the NGSS and whether they were Lead States in the development of the NGSS or not.

The discourse-rich environments also offered social resources (Cohen et al., 2003) in the form of collaborative working groups, access to experts, and research practice partnerships. These social resources offered spaces for the co-construction of meaning around the ideals espoused in the *Framework* and NGSS. Consistent with prior work showing the key role CSSS played in brokering access to researchers and research opportunities for members (Hopkins et al., 2018), CSSS also emerged in our data as a central organization that supported SSCs' ongoing sense-making. Many SSCs reached out to their colleagues in CSSS to puzzle over challenges, connect with research and researchers, and collaborate with colleagues. This reliance on professional networks not only as conduits of reform messages but also as brokers of research, researchers, and research practice partnerships is consistent with findings about school leaders' access to education research through their professional networks (Penuel et al., 2017). Indeed, these data suggest that SSCs were relying on the "actual, imagined, or implied presence of others" (Allen & Penuel, 2015, p. 137) as they engaged with their colleagues in CSSS.

The centrality of professional networks in SSCs' accounts of their efforts to reform science education may in part reflect the social-movement-like nature of the effort. In the absence of federal directives or inducements around science education, state leaders' connections to professional networks enabled them to not only learn about national agendas, but to collectively advocate on behalf of said reform movements (Hardy & Campbell, 2020). Professional networks provided a space where SSCs learned about reform messages and connected with leading researchers in the field. As such, professional networks appear to provide an important link between state-level policy contexts and the broader national reform agenda, in this case. It also underscores a familiar theme in education reform in the United States—the critical role that non-governmental organizations (NGOs) like the CSSS play in supporting reform efforts (Burch, 2009; DeBray-Pelot & McGuinn, 2009; Marsh & Wohlstetter, 2013).

5.3 | Elementary science education reform as a national movement

One theme evident in our analysis concerns the social-movement-like nature of recent reform efforts in elementary science. Social movements are "networks of informal interactions between a plurality of individuals, groups, and/or organizations, engaged in political or cultural conflicts, on the basis of shared collective identities" (Diani, 1992, p. 1). Our account can be understood as capturing how a national movement, designed to allow for state variation in the standards themselves, contributed to the building of remarkable consistency across SSCs' understandings about reforming elementary science. This contrasts with the rollout of the Common Core State Standards in ELA and mathematics in 2009–2010. Although the "national" development of the Common Core was relatively smooth, implementation in states and local school districts generated friction and outright opposition (McDonnell & Weatherford, 2016).

From the standpoint of social movement theory, this friction of the Common Core roll-out might be understood as a destabilizing shock to proximate fields of education including the field of science education (Fligstein & McAdam, 2011). Skilled social actors who were spread across an array of government and non-government organizations within the field of science education—including CSSS; Achieve; NSTA; and the National Research Council (NRC), now known as NASEM—may have seen this as an opportunity to advance a collective agenda for science education reform. To this end, actors brought together by the NRC proposed a new *Framework for K-12 Science Education* (National Research Council, 2012), and skilled actors brought together by Achieve subsequently released the NGSS (NGSS Lead States, 2013). These efforts were dissociated from federal policy and resources. The *Framework* and the NGSS were then, in turn, supported by actors within (and influenced by) CSSS, who shaped their uptake and use. SSCs in our study repeatedly referred to their states' processes of adopting the Common Core State Standards as a cautionary tale, mentioning lessons learned in that process that they wanted to be careful not to repeat with state science standards and NGSS, in particular avoiding the process getting tangled in rhetoric around federal overreach (Hardy & Campbell, 2020).

Relatedly, social movement theorists emphasize the importance of social movement organizations in mobilizing key resources (e.g., money, labor, and time) to effect change (Fligstein & McAdam, 2011; McCarthy & Zald, 1977). Contrary to popular beliefs about grassroots movements being organized by community members around local concerns, one might view CSSS as a social movement organization, mobilizing an "established elite group" (McCarthy & Zald, 1977, p. 251) to press a national science education reform movement. Key resources mobilized by CSSS included access to core principles of elementary science reform, access to materials and data, and access to partnerships for advancing reform agendas.

While SSCs may be part of a social movement, they are also state government policy actors and work in an environment that constrains their approach to reform. Indeed, the dissociation of NGSS from federal policy creates unique implementation challenges. Absent federal policy incentives, support, and associated resources, getting NGSS and elementary science education reform more broadly on the policy agenda, especially the local school district and school agenda, may be challenging for SSCs. At the same time, SSCs, though "members" of a national movement, must rely on conventional government policy instruments to advance the reform of elementary science. As such, national efforts to reform science education face something of a quandary with science reformers wanting to keep federal involvement at bay, while at the same time needing to find ways to get science prioritized in state and local government policy agendas. We are exploring this line of analysis in ongoing work.

5.4 | Implications for policy and practice

The rollout of the NGSS was designed to avoid perceptions of federal overreach that plagued the Common Core (Hardy & Campbell, 2020). Our account suggests two key lessons for policy and practice from this national reform movement. One lesson is that allowing states more flexibility and agency to adopt or adapt their own state standards—albeit buoyed by a well-developed professional network supporting SSCs' ongoing sense-making about improving science education—cultivated a state-driven rather than federally-driven reform approach. Allowing states to adapt their own standards also enabled SSCs to skirt difficult state politics that often emerge at the policy implementation stage (McDonnell & Weatherford, 2016). Furthermore, our analysis uncovered no systematic differences between SSCs' understandings of the reform ideas in NGSS-adapting relative to NGSS-adopting states.

A second lesson involves the *Framework* and its role as a guiding material resource for policymakers to attend to, alongside the specifics of the NGSS, as they engaged in sense-making about reforming science education. The *Framework* was a key boundary object, shared across states, professional organizations, and stakeholders (Star, 2010), that SSCs repeatedly referenced as central to their efforts to understand reform ideas and work out their entailments for elementary science education.

However, the flexibility and agency afforded to states under this national NGSS movement also complicated state efforts to improve elementary science instruction. Disassociating the NGSS from federal policy that might have mandated attention to elementary science, meant that many SSCs had limited tools and resources to get local school districts and schools to pay attention to the state of elementary science instruction. For further description of the tools and resources SSCs are leveraging, see reports from Hopkins (2016) and Hopkins and Gates (2018).

For science education researchers interested in engaging with state-level policymakers, our findings offer two additional takeaways. First, our findings point to potentially promising entry points for engaging SSCs in ongoing sense-making about science education reforms. For example, SSCs are broadly on board with 3D learning, but in many cases, more support is needed to conceptualize what it looks like instructionally to integrate the crosscutting concepts. Efforts such as those put forward in the Summit for Examining the Potential for Crosscutting Concepts to Support 3D Learning (Fick et al., 2019) could be translated into practitioner-facing presentations and reports to further SSCs' sense-making about all three dimensions of science learning.

Secondly, our findings point to potentially promising levers to engage for reaching SSCs and influencing their sense-making. For example, CSSS is a highly influential professional network with which almost all the SSCs in our study engaged. The ACESSE project is a research-practice partnership involving the University of Washington, the University of Colorado, Boulder, and the CSSS. The newest iteration of ACESSE involves representatives from each state in critical conversations about racial justice and equity in science education (Garcia et al., 2021, April 7–10). The use of CSSS as a lever for this sense-making may make a real difference in how SSCs think about equity beyond a focus on access and opportunities.

In conclusion, we see a confluence of factors—ranging from (a) established and robust professional networks for SSCs to (b) the development of the *Framework* as a guiding document to (c) the dissociation of the implementation of NGSS from federal mandates—as contributing to consequential sense-making around reform ideas that resulted in shared ideas about elementary science priorities across the nation. These are important steps toward improving elementary science instruction, and yet the challenge of prioritizing elementary science instruction amidst a noisy education policy context remains a critical puzzle to solve for policy makers and educators alike.

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ENDNOTES

[1] We understand "federal" to be linked to policies or initiatives from the US federal government, as opposed to "national" which we understand as nationwide efforts in the United States not directly associated with the federal government.

[2] Occasionally, a pseudonym will have a number at the end, indicating that more than one state in our sample has the same set of characteristics.

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