Introduction

The Study of System-Building for Elementary Science Instruction

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Introduction:
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What is the path from the Next Generation Science Standards as a policy instrument to ambitious science learning in elementary classrooms?

Since the introduction of standards as a policy instrument in the 1980s and 1990s, an assumption shared among many reformers is that the path from aspirational standards to ambitious student learning runs through teachers. By this assumption, standards guide teachers in organizing instruction: selecting, designing, and coordinating content, topics, tasks, assessments, norms, and students' and teachers' roles. Standards guide teachers in managing instruction: adapting, adjusting, and responding dynamically in response to interactions and outcomes. And standards guide teachers in improving instruction: in raising quality, by setting higher expectations; and in advancing equity, with these higher expectations the norm — that is, the standard — for all students.

This line of reasoning is anchored more fundamentally in the assumption that more and better resources will drive more and better student learning (Peurach, Foster, Lyle, & Seeber, 2022).[1] And that is where the focus turns: toward developing more and better standards to guide teachers; more and better curriculum that embody the standards and support their implementation; and more and better knowledge and capabilities in teachers to operationalize and realize the standards. This resource-forward logic did not materialize with the advent of standards. Rather, it dates to earliest years of public education in the United States. In science education, this logic was integral to initial efforts in the 1950s of the newly-created National Science Foundation to improve instruction and student learning: a strategy of "texts and teachers", and of funding their development (Kahle, 2007).

We accept that more and better resources are necessary, and even common sense. But we are concerned that they are not sufficient, and that there is more to the story. The new "more" that we have in mind has not been common sense among many people, including many in the science education reform community. But this new "more" is coming into view, broadly and among the science education reform community.

We report here on a study anchored in a different assumption that aims to illuminate this new "more": the assumption that the path from aspirational standards to ambitious student learning runs through organizations — public school districts, specifically; their central offices and schools; and their work organizing, managing, and improving instruction. By this assumption, a positive return on aspirational standards depends on more districts, central offices, and schools working in collaboration with more teachers to operationalize and realize aspirations for educational quality and equity in-and-through instructional practice.

Districts have a complicated present: They are working in interaction with fragmented and turbulent political, policy, and social environments that place multiple, simultaneous, competing, and often contradictory demands on their work. Districts have a complicated past: They have worked in interaction with these environments over decades (if not centuries) preceding the advent of standards as a policy instrument, amidst social disagreement on what all students should learn, how all students should learn, and whether all students could learn. As creations and mirrors of these environments, the effect is that many districts have accumulated structures, routines, and norms that challenge (if not undermine) the pursuit of educational equality and equity. That is why some assume that operationalizing and realizing aspirational standards requires working *around* districts -- and not *through* districts -- with a path that runs directly to teachers.

By this second line of reasoning, districts are part of the solution; districts are part of the problem. Again, these understandings are not common sense. These understandings are coming into view. Our aim is to illuminate them further.

We continue, then, by introducing The Study of System-Building for Elementary Science Instruction.

The Next Generation Science Standards

The Next Generation Science Standards (NGSS) were released in April 2013 as K-12 science content standards (National Research Council, 2013). These standards are expressed as performance expectations that integrate scientific practices, core concepts, and disciplinary core ideas: a design that, in its 2012 *Framework for K-12 Science Education Standards*, the National Research Council described as "three dimensional learning" (National Research Council, 2012). We describe such science learning as *ambitious*, in that it aims for students and teachers to collaborate in understanding and enacting scientific practices, concepts, and ideas in ways that are rigorous, consequential, just, and equitable (Davis & Haverly, 2022).

The brand mantra of the NGSS is that they were developed "for states, by states": more specifically, a consortium of 26 states, in collaboration with the National Science Teachers Association, the American Association for the Advancement of Science, and Achieve. To date, 20 states plus the District of Columbia have adopted the NGSS; an additional 24 states have developed their own standards based on the NRC Framework (National Science Teachers Association, 2022).

The goal of the NGSS is not to prescribe instructional practice. Instead, the goal is to provide guidance to local educators that can be used flexibly in designing learning experiences that both stimulate students' interest in science and prepare students to continue engaging science in college, in their careers, and as citizens. The vision of the NGSS is that thoughtful and coordinated approaches to implementation will enable educators to inspire future generations of scientifically literate students (NGSS Lead States, 2022b).

The NGSS were designed to challenge traditional science instruction focused on the didactic teaching and passive learning of scientific facts and skills. The NGSS were not designed to challenge the formal governance structure of US public education. Rather, they were designed to work within that structure, with little (if any) federal role, a modest (but essential) state role, and considerable local autonomy, discretion, and initiative. The NGSS consortium stated explicitly that the federal government was not involved in the development of the NGSS, and that the initiative did not use federal funds (NGSS Lead States, 2022a).

The NGSS aim to reduce disparities and to advance equity in-and-through ambitious science learning -- not as a privilege for some students, but as the standard for all students (NGSS Lead States, 2013). They aim to prepare students for academic and professional careers that advance and leverage scientific knowledge and practices. They aim to empower students as responsible and engaged citizens in a dynamic and often-turbulent world.

Most fundamentally, the NGSS aim to stimulate students' curiosity and motivation by experiencing wonder, discovery, and joy through ambitious, three dimensional science learning. That is the aim on which all others rest. For unless all students develop the curiosity and motivation to learn science, and unless they sustain that curiosity and motivation, the prospects of realizing aims for equity, employment, empowerment, and engagement wane.

Teachers

That fundamental aim becomes a fundamental responsibility of elementary school teachers: to design and enact science learning experiences in classrooms through which all students experience wonder, discovery, and joy. This is a responsibility to be pursued from the moment little children first walk through the doors of elementary schools and become students to the moment those students head out for middle school and beyond, such that all students leave elementary school with the curiosity and motivation to continue learning science (and the knowledge and capabilities, too). Indeed, among the distinguishing features of the NGSS is the focus on ambitious science learning in elementary schools: not in a single, tested grade level but comprehensively, from kindergarten through 5^{th} grade.

If that is a fundamental responsibility of elementary school teachers, it is a responsibility that, at the time the NGSS were released, far outpaced the professional preparation of most elementary school teachers. Teacher certification requirements and professional teaching standards in the US had long placed weaker demands on subject-specific knowledge for elementary school teachers as compared to middle and high school teachers, never mind requirements and standards that all elementary teachers be proficient in integrating scientific practices, core concepts, and disciplinary core ideas into ambitious science learning experiences for all students.

Consider that, at the time the NGSS were released in 2013, the National Science Teachers Association (NSTA) recommended that US elementary teachers complete one course each in life science, earth science, and physical science. In 2014, in its *Science and Engineering Indicators* report, the National Science Board (NSB) reported that 38% of US elementary teachers had completed the three recommended courses; that 39% had completed two of the three; that 20% had completed one; and that 3% had completed none (National Science Board, 2014). Put differently: At the time that the NGSS were released in 2013, 62% of elementary teachers did not meet the NSTA's basic course requirements for teaching science. Moreover, the NSB reported that only 5% of elementary teachers had a college degree in science, engineering, or science education.[2]

It is little wonder that the NSB would also report, in 2012, only 39% of elementary teachers felt very well prepared to teach science, as compared to 77% feeling very well prepared to teach mathematics (National Science Board, 2014). The implied reference point is “teaching science” as traditionally practiced in 2012 and prior, and not in ways that center the three dimensional learning of the NGSS. By the NGSS consortium’s own critique, these traditional practices focused on the didactic teaching and passive learning of scientific facts and skills.

Organizations and Environments

By this line of reasoning, the aims of the NGSS resolve into the seemingly impossible: many elementary teachers expected to design and enact ambitious science learning for all students absent requisite knowledge and capabilities, and likely having experienced little wonder, joy, and discovery in science learning, themselves. None of this is to mention teachers’ additional responsibilities for instruction in other content areas; for attending to students’ physical, social, and emotional well-being; or for attending to students’ moral and ethical development.

But this mismatch between high level ambitions and individual knowledge, capabilities, and motivations is not unique to the NGSS and to elementary school teachers. To the contrary, it is endemic in contemporary society. Ambitions for advancing public health fall on the shoulders of individual nurses and doctors. Ambitions for athletic accomplishment fall on the shoulders of individual players. Ambitions for profits and quality fall on the shoulders of individual workers. And ambitions for creating heaven on Earth fall on the shoulders of individual sinners.

But if the mismatch is endemic, its resolution is ubiquitous: organizations; collectives of people that structure and support, both intentionally and incidentally, the pursuit of shared goals, social interactions, and engagement beyond the collective.[3] Indeed, nurses and doctors are members of clinics and hospitals; players are members of teams; workers are members of firms; and sinners are members of churches. In contemporary society, organizations are among the primary means of pursuing the seemingly impossible, given individual limits in knowledge, capabilities, and motivation, certainly, but also in reasoning, time, and contribution.

By this second line of reasoning, the aims of the NGSS do not resolve into the impossible. Rather, they resolve into organizations. Simon (1969) famously described human organizations of the sort ubiquitous in contemporary society as artificial, and not natural: as creations of people in interaction with their environments, with people, environments, and organizations co-evolving.[4] Organizations are mutable: People have agency in structuring organizations in interaction with environments. Organizations are deterministic: Their goals structures pattern interactions among people.[5]

Of particular interest and importance are the organizations in which children are compelled by law to spend up to 13 years of their lives and in which most elementary teachers take up their day-to-day work: public school districts, and their central offices and schools. These organizations exist in environments: local communities, under state authority, with tenuous federal sway. These organizations structure and support, both intentionally and incidentally, the pursuit of shared goals among students and teachers; social interactions among students and teachers; and engagement with broader environments. And these organizations are both mutable and deterministic, and such that they can developed, formed, and re-formed in ways that pattern interactions that advance policy and societal aspirations for educational quality and equity.

By this second line of reasoning, pursuing the seemingly impossible aims of the NGSS depends heavily on the work of districts, their central offices, and their schools in organizing, managing, and improving the day-to-day work of elementary school teachers to ensure ambitious science learning for all students. That is, after all, the type of work that most people assume districts, central offices, and schools to do. That is, after all, the design of the NGSS: considerable local autonomy, discretion, and initiative; a modest (but essential) state role in establishing and advancing standards; and little (if any) federal role.

Contemporary Complications

Just as organizations can structure and support, they can also impede and undermine. So, too, the environments in which organizations exist. At the time that the NGSS were introduced, district central offices, schools, and broader policy contexts were interacting to do exactly that: impede and undermine ambitious student learning in elementary science.[6]

The NGSS were introduce into a national education enterprise in the throes of transformation, with state standards and accountability pressing hard on central offices and schools to improve achievement and to reduce disparities in students' learning in English/language arts and mathematics. This press had roots in increased federal engagement in advancing quality and equity in public education, including successive reauthorizations of the Elementary and Secondary Education Act (ESEA) in 1995 (as the Improving America's Schools Act) and 2001 (as the No Child Left Behind Act).

These reauthorizations had two new and important provisions. The first was incentives, resources, and guidance for states to establish performance standards and associated accountability provisions for schools and, later, districts. The second was opportunities for schools serving large numbers of poor students to use federal funding to support school-wide (vs.

categorical) improvement programs, with whole schools (vs. individual students) the units of improvement. Indeed, absent constitutional authority, incentives, resources, and guidance were (and remain) federal policy instruments of choice in eliciting reform activity in states, districts, and schools.

Policy consensus around standards, accountability, and whole school reform had begun building in the 1980s and early 1990s: for example, with onset of the effective schools movement in the early 1980s; the Hawkins-Stafford Amendments to ESEA in 1988; the Charlottesville Education Summit in 1989; the publication of the National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards in 1989; and the publication of Marshall Smith's and Jennifer O'Day's seminal treatise on systemic school reform in 1990. The policy press of standards, accountability, and whole school reform has continued since: for example, with the launch of the federal Race to the Top challenge of 2009; the onset of the Common Core State Standards initiative in 2010; and the reauthorization of ESEA as the Every Student Success Act in 2015.

Science had been in the mix throughout (Atkin & Black, 2007; DeBoer, 2014; Kahle, 2007). For example, the American Association for the Advancement of Science (AAAS) launched Project 2061 in 1985 as a long-term research and development project aimed at improving science education. AAAS quickly followed with the publication of *Science for All Americans* in 1990, *Benchmarks for Scientific Literacy* in 1994, and *Blueprints for Reform* in 1998. The work of AAAS was complemented by the work of the National Research Council, and its publication of *National Science Education Standards* in 1996 and *Common Standards for K-12 Education Reform* in 2008.

Even so, the federal reauthorization of ESEA as the No Child Left Behind Act of 2001 did more to incentivize and resource the development of state standards and accountability for English/language arts (ELA) and mathematics than it did for science: specifically, annual testing in ELA and mathematics in grades 3 through 8, and at least once in high school; and testing in science at least once in grades 3 through 5, grades 6 through 9, and grades 10 through 12 (May et al., 2009. These provisions remained unchanged with the reauthorization of ESEA as the Every Student Succeeds Act of 2015. States followed suit, with Common Core State Standards initiative focused on ratcheting up the rigor of standards in ELA and mathematics (and not science).

Districts and schools followed suit, as well. With federal and state standards and accountability pressing hardest for rigor and improvement in ELA and mathematics, that is where many districts and schools directed their time, energy, and resources. In elementary schools, this was often at the expense of commensurate time, energy, and resources being devoted to advancing rigor and improvement in science and social studies, never mind time and opportunity for students to grow and develop in art, music, physical education, and the library (National Academies of Sciences Engineering and Medicine, 2021b). Indeed, a common lament among teachers, families, and critics was that the press of standards and accountability in ELA and mathematics were draining elementary schools of the very wonder, discovery, and joy that the NGSS aimed to engender.

Yet it is a mistake to attribute this academic press exclusively to the federal and state policy press of standards and accountability. Rather, standards-and-accountability was but one of many policy logics pressing districts and schools to increase quality and to reduce disparities in students' learning. Policy logics and associated initiatives centering excellence-and-equity, markets-and-choice, data-and-evidence, and professionalism-and-autonomy had emerged, advanced, and evolved concurrent with standards-and-accountability. Collectively, these policy logics pressed hard (and continue to press hard) on districts and schools to develop new capabilities to improve quality and to reduce disparities in students' educational opportunities, experiences, and outcomes.

Legacy Complications

So, too, is it a mistake to attribute the focus in elementary schools on ELA and mathematics exclusively to the onset in the 1990s of federal and state standards and accountability. Rather, the focus in elementary schools on ELA and mathematics is centuries-old. Moreover, this centuries-old focus on ELA and mathematics was but one of many legacy complications impeding efforts to improve science instruction.

The "three Rs" (reading, writing, and arithmetic) have long been culturally recognized as the basic skills to be taught in elementary schools. Indeed, the very founding of public education in the US is widely recognized as a series of laws passed in the 1640s in the Massachusetts Bay Colony required towns with 50 or more families to hire a schoolmaster to teacher all dependent children to read and write, with literacy instruction associated with religious and civic engagement. By the 1690s, a commercial resource market began emerging to provide textbooks that structured a primary-grade curriculum supporting instruction in reading, spelling, and grammar. Mathematics followed, with the emergence of a commercial resource market in the 1830s that provided textbooks structuring primary-age instruction in mathematics.[7]

By contrast, early science instruction in elementary schools leveraged children's literature, not commercial textbooks (Atkins & Black, 2007). Texts supporting nature study only began emerging in the late 1800s. Commercially published textbooks structuring a coordinated, cross-grade elementary science curriculum were first introduced in the 1930s (Champagne & Klopfer, 1980; Underhill, 1941). The quality and rigor of conventional textbooks were sufficiently low as to motivate one of the earliest federal efforts to intervene in classroom instruction: curriculum and professional development projects funded by the National Science Foundation beginning in the 1950s, soon after its founding. With that, the federal government had entered the resource market: not as a provider, but as an investor.

Just as the focus on ELA and mathematics had roots preceding the onset of federal and state standards and accountability, so, too, did a ubiquitous approach by districts and schools to organizing, managing, and improving instruction: sorting, resourcing, and delegating.[8] Central offices sorted students into schools, and schools sorted them into grade levels, academic tracks, regular classrooms, and compensatory instructional venues for struggling students and students with special needs. They resourced those venues with teachers, guidance, textbooks, and instructional materials. And they delegated to individual teachers the primary responsibility for organizing, managing, and improving their day-to-day instructional work with the students assigned to them using resources provided to them.

This approach to organizing, managing, and improving instruction was responsive to the most sustained and fundamental societal and policy press on districts and schools: to provide increasing access to schooling for increasing numbers of increasingly diverse students, including students of poverty, students of color, and students with disabilities who had long been excluded and marginalized. Pre-dating the establishment of state standards, this approach was responsive to the lack of social consensus on what and how these students would learn, or even that all of them could learn — thus, political risk to central office and school leaders for taking a stand on such matters. And this approach was also responsive to widely-held notions of teacher professionalism as grounded in teachers' individual autonomy over classroom work.

Yet, from the perspective of elementary science instruction, this approach to sorting-resourcing-and-delegating by districts and schools meant that elementary teachers who lacked preparation and confidence had responsibility for organizing, managing, and improving science instruction for increasingly diverse students using either familiar, low quality, commercially-published textbooks or unfamiliar, ambitious, federally-funded curriculum resources.

As organizations, districts and schools were structurally-elaborated public bureaucracies that inspired confidence, drove local property values, secured local tax levies, and garnered their communities' most precious resource: children. Yet while these public bureaucracies did much to manage *schooling*, they did little to manage *education*. Indeed, among the primary (and most surprising) findings of early sociological investigations of educational organizations in the 1960s and 1970s was a "loose coupling" between the formal structure of districts and schools as organizations and the behavioral structure of teachers and students in classrooms (Bidwell, 1965; Meyer & Rowan, 1978; Weick, 1976).

Rather, responsibility for the day-to-day work of learning and teaching in the US was the province of teachers working behind the closed doors of their own classrooms, exercising professional autonomy in professionally isolation from colleagues, and often teaching not in ways that reformers imagined but, instead, in ways in which they, themselves, were taught (Dreeban, 1973; Jackson, 1968; Lortie, 1975). For many elementary school teachers responsible for organizing, managing, and improving science instruction, that would mean didactic teaching and passive learning of scientific facts and skills.

With that, the markets that had formed in broader environments of districts and schools were recreated within them, and in ways that favored the privileged over the disempowered. In elementary schools, one well-worn strategy for improving prospects for students' success was for families to go shopping for the best individual teacher at their child's grade level, and to advocate for their students' placement in her or his class. Comprehensive public high schools were likened to educational shopping malls: value-neutral on what comprised or qualified as a standard, high quality education for all students; ripe with a wide variety of choices of teachers' own design; and supporting choice by students and families in constructing an education of their own design (Powell, Farrar, & Cohen, 1985). More resourceful and engaged families with students were better able to leverage educational opportunities navigated these markets to more advantage; others, to less advantage.

But it was not only broader markets that were recreated within districts and schools, nor inequities navigating markets to personal advantage. Rather, social inequality in the environments of public education was created in-and-through public education. For example, consider:

- De jure and de facto segregation had students sorted among districts and schools by race, ethnicity, and social class, and sorted further within schools among academic and vocational tracks (Gamoran & Mare, 1989; Oakes, 1985).
- Dependence on local funding for public education drove inequities in resources among districts, and restrictions on the use of supplemental federal funding drove the creation of new compensatory venues into which to sort students: for example, Title I, special education, ELL/ESL, and vision and hearing impaired (Allington & Johnston, 1989).
- While responsibility for organizing, managing, and improving instruction was largely delegated to individual teachers, labor market dynamics resulted in the over-representation of poorly-trained and less-qualified teachers in districts, schools, and classrooms serving large numbers of poor, minority, and special education students (Lankford, Loeb, & Wyckoff, 2022; Jacob, 2007).

Such was structural inequality as manifest in districts and schools, and in the work of organizing, managing, and improving instruction. This structural inequality ran through the organization, management, and improvement of science instruction, especially in high schools: for example, in the early 1900s, with variation in content and rigor of science instruction among newly-developed (and subsequently institutionalized) college preparatory, vocational, and life skills tracks; in the 1950s, with federal investment in gifted and talented programs (and associated resources) in response to the onset of the Cold War; and in the 1970s and 1980s, with the onset of course-based graduation requirements and student competency testing, and the proliferation less-rigorous and remedial science courses for non-college bound students (Atkin & Black, 2007; DeBoer, 2014; Kahle, 2007). Such structures did more to exacerbate (rather than to mitigate) differences in students' science learning in elementary schools.

Reconsideration

Contemporary and legacy complications beg reconsideration of the effects of standards and accountability in ELA and mathematics on the work of districts in organizing, managing, and improving instruction. Indeed, standards and accountability are two sides of a coin. From one perspective, standards and accountability in ELA and mathematics are impeding and undermining efforts to advance ambitious learning and teaching in elementary science. From another perspective, standards and accountability in ELA and mathematics suggest a path forward.

The decades-long press of standards and accountability appears to be interacting with other, sustaining policy logics and initiatives to disrupt a deeply institutionalized, often-inequitable pattern of instructional organization, management, and improvement in districts.[9] To be sure, central offices and schools continue to sort students into new categories; to improve their learning opportunities by acquiring and allocating new resources; and to delegate responsibility for students' learning to teachers. Such work is integral to mass public schooling that ensures universal access to all students. Even so, the decades-long press of standards and accountability also has many central offices and schools collaborating with each other and with teachers to organize, manage, and improve the educational opportunities, experiences, and outcomes of all students in ways responsive to socially agreed-upon standards for students' learning.

Indeed, in ELA and mathematics, districts are showing signs of evolving beyond *school systems* that simply sort, resource, and delegate to *educational systems* that also organize, manage, and improve classroom instruction with the aims of improving quality, reducing disparities, and advancing equity. Far beyond reallocating instructional time to ELA and mathematics, this has central offices and schools beginning to develop capabilities for (and to engage in) domains of work that were uncommon for most of the history of US public education (Peurach, Cohen, Yurkofsky, & Spillane, 2019). These include:

- *Managing environmental relationships* to bridge, buffer, and reconcile among the many cultural, political, and technical influences bearing on how the district understands and pursues quality and equity in instruction (e.g., family/community aspirations and values, federal and state policies, philanthropists' agendas, and educational research).
- *Building educational infrastructure* that coordinates visions for instructional practice, formal instructional resources (e.g., instructional models, curricula, and assessments), and social instructional resources (e.g., norms, values, and relationships among students, teachers, and leaders).
- *Supporting the use of educational infrastructure in practice* by developing teachers' professional knowledge and capabilities through coordinated workshops, practice-based coaching and mentoring, and collegial learning.
- *Managing performance* for continuous improvement (e.g., via evidence-driven design, implementation, and evaluation) and for accountability (e.g., via the use of evidence and standards to assess instructional processes and outcomes) to advance and assess positive interdependence in the work of managing environments, building infrastructure, and supporting use.

- *Developing and distributing instructional leadership* beyond established administrative roles to new leadership roles and structures responsible for performing, coordinating, and managing all of the preceding.

The work of moving beyond school systems to education systems is *institutional work*.[10] In strategic terms, institutional work is "the purposive action of individuals and organizations aimed at creating, maintaining, and disrupting institutions" (Lawrence & Suddaby, 2006:215). In pragmatic terms, institutional work is "the efforts of individuals and collective actors to cope with, keep up with, shore up, tear down, tinker with, transform, or create anew the institutional structures within which they live, work, and play, and which give them their roles, relationships, resources, and routines" (Lawrence, Suddaby, & Leca, 2011).

In this case, the institution being disrupted, tinkered with, and transformed is sorting-resourcing-and-delegating as a structurally embedded, culturally accepted, yet often dysfunctional and inequitable approach to organizing, managing, and improving instruction. The tinkering-and-transformation lie in the introduction of new, interdependent domains of work in districts, central offices, and schools that aim to mitigate dysfunction and inequity and to advance quality and equity. Institutional work of this sort is *technical*, and focused on developing capabilities and improving performance; *cultural*, and focused on both establishing and challenging norms, values, and beliefs; and *political*, and focused both on the just use of power and on empowering just practice (Lawrence & Suddaby, 2006; Perkmann & Spicer, 2008; Scott, 1995).

The work of moving beyond school systems to education systems is not only historically novel in the US public school enterprise. It is also fraught with dilemmas, puzzles, and challenges (Cohen et al., 2014; Cohen, Spillane, & Peurach, 2018; Peurach, Yurkofsky, & Sutherland, 2019). For example, such work has districts wrestling with distributing and coordinating responsibilities among central offices and schools; weighing the advantages of acquiring or developing essential educational resources; balancing the advantages of standardizing operations with traditions of (and needs for) for discretion and differentiation; and building the consensus needed for coherent action while respecting diverse perspectives among all involved.

Moreover, such work is playing out amidst legacy complications as manifest in ELA and mathematics, with new ambitions for instructionally-focused education systems colliding with the institution of (and systemic inequities in) mass public schooling (Peurach, Cohen, Yurkofsky, & Spillane, 2019). This is what may be the summary dilemma of institutional work: the "paradox of embedded agency" (Garud et al., 2007). The dilemma lies in shedding the cognitive, normative, and regulative constraints of the status quo as internalized and as externally reinforced; and using evidence, ideas, and reason to fashion a sense, schema, or blueprint of what does not yet exist, but might.

Thus, in ELA and mathematics, the path from standards as policy instruments to improvement in instructional practice appears to run through organizations. But it is not a well-worn path. Rather, it is a new path blazed through old organizations: districts, central offices, and schools. These organizations are artificial; they are creations of people. These people and the organizations that they create exist in broader environments. And these people appear to be recreating these organizations to pursue new goals in ways responsive to dynamics in their environments. They are feeling strain and the pain. Progress is slow and measured, and sometimes thwarted. Such is blazing new paths.

Emerging Understandings

The preceding analysis supports a conjecture in response to the question that motivated it: *The path from the Next Generation Science Standards as a policy instrument to ambitious science learning in elementary classrooms runs through districts, central offices, and schools.* This would not be a path followed but a path blazed through the collaborative work of managing environmental relationships, building educational infrastructure, supporting the use of infrastructure in practice, managing performance, and developing and distributing leadership. It is a path along which districts evolve from *school systems* to *education systems*.

To the extent that this conjecture is on the mark, then the research literature on science education reform provides scant guidance for moving forward. For example, a content analysis of publications in the journal *Science Education* from 1916 to 2019 using natural language processing identified “science learning in museums and other informal settings” as one of 21 distinct topics addressed in depth (Odden, Marin, & Rudolph, 2021). By contrast, the analysis did not identify any other topics focused on science learning in districts, systems, or other organizational contexts. A complementary content analysis of trends in science education research published in four leading journals (*International Journal of Science Education*, *Journal of Research in Science Teaching*, *Research in Science Education*, and *Science Education*) from 1990 to 2007 identified nine core topics, none of which were organization-focused (Chang, Chang, & Tseng, 2010).

Indeed, in a review of research on systemic reform in science, Kahle (2007) argued that the shallow research base is, in part, a consequence of a lack preparation among science education researchers in studying change and improvement in large-scale education systems. Yet it is on exactly such change and improvement on which the fate of the NGSS appear to rest.

Even if not a central focus of science education *researchers*, the understanding that districts, central offices, and schools play a key role in advancing quality and equity has been growing and strengthening among science education *reformers* since at least the 1990s. The seeds of this understanding are evident in the NSF-funded Statewide Systemic Initiatives of the 1990s, the logic model of which had states supporting districts and schools in developing capabilities to support instruction and student outcomes in science (Zucker et al., 1998). Moreover, while its proponents have long recognized that operationalizing the NGSS would depend on local autonomy, discretion, and initiative, growing evidence suggests that these proponents, themselves, are coming to a fuller understanding of what that means for both a) the work of central offices and schools and b) the policy instruments needed to motivate that work. For example, consider:

- Since the release of the NGSS, the NextGenScience project at WestEd (the coordinating center for the NGSS) has collaborated with Achieve, the National Research Council, and others to accumulate a suite of implementation and professional learning resources to support states and districts in implementing the NGSS, including a district implementation guide and associated workbook and indicators (NGSS Lead States, 2022c).
- Between 2014 and 2020, the Bechtel Foundation funded the NGSS Early Implementers Initiative in which the K-12 Alliance at WestEd supported NGSS implementation in eight California districts, with a specific focus on K-8 instruction. The initiative yielded a series of reports providing guidance for districts and schools in operationalizing the NGSS, including guidance both on district planning and on the role of district and school leadership (Bechtel Foundation, 2022).[11]
- In 2021, the National Academies of Sciences, Engineering, and Medicine published a consensus report summarizing research on science and engineering education in pre-school through the elementary grades (National Academies of Sciences, Engineering, and Medicine, 2021b). The report includes a comprehensive heuristic that elaborates components of (and relationships among) states, districts, and schools bearing on the implementation of the NGSS, as well an analysis of transformative district and school leadership as developing organizational culture, policy and management, and educator capacity in ways that support NGSS implementation.

- In a 2021 call to action, the National Academies of Sciences, Engineering, and Medicine recommended (among other things) for both the federal government and state governments to raise the press of assessments and accountability in science education, including incorporating science as an indicator of academic achievement in the next reauthorization of the federal Elementary and Secondary Education Act (National Academies of Science, Engineering, and Medicine, 2021a).

Our Study

The preceding analysis suggests both need and opportunity to investigate the role and work of districts in organizing, managing, and improving elementary science instruction. One matter for investigation is the work of states in cultivating and supporting district engagement in mediating between the NGSS as a policy instrument and ambitious science learning in elementary classrooms. Among districts that are engaging, a second matter for investigation is the work of districts in building or rebuilding themselves as education systems that support teachers in organizing, managing, and improving elementary science instruction with the aims of advancing both quality and equity. A third matter for investigation centers on identifying dilemmas, puzzles, and challenges that arise through the work of system building and rebuilding, and the ways that districts attempt to manage and to mediate them.

We are taking up these three matters in a National Science Foundation-funded study exploring the work of developing coordinated school- and system-level elementary science learning environments in response to the *Framework for K-12 Science Education* (National Research Council, 2012) and the Next Generation Science Standards (National Research Council, 2013). Using an embedded, comparative case study design, we are analyzing efforts in 13 districts in six states to bridge from NGSS learning ideals to classroom instruction. We are studying these efforts over five years, incorporating different levels of analysis (i.e., state, district, school, classroom) each year while continuing to study earlier levels.

The following is an interim report focused on the second of the three matters identified above: the work of districts in building or rebuilding themselves as education systems that support teachers in organizing, managing, and improving elementary science instruction with the aims of advancing both quality and equity. More specifically, we report on district-level data collected in years two and three of the study with respect to three case study districts – one urban, one charter, and one suburban district.

Sample Selection

We began our sample selection by first identifying six states that had active policy environments for elementary science. To select these states, we asked experts and leaders in elementary science, including leaders in state departments of education, higher education, and national and regional organizations, to identify states and individuals engaged in elementary science reform. Using a snowball sampling method, we gathered nominations and input from 62 elementary science leaders. We then ranked the states based upon number of nominations to identify those states that had more and less active environments for elementary science as recognized by leaders in the field. We conducted interviews with a subset of those states to further learn about their system-building efforts related to elementary science (see Haverly et al., 2022 and Lyle et al., 2022 for state-level analyses). From our analysis of state-level data, we selected six states that we identified as having active state policy contexts for elementary science.

We then identified and recruited school districts in each of our case study states. We began by reaching out to leaders in science reform within these states (~n=150) to gather recommendations for districts engaging in system-building in elementary science. From these recommendations, we researched and spoke with district-level leaders in roughly 45 districts to learn about their system-building efforts in elementary science. We also gathered demographic and other information about district organization and elementary science initiatives for each district under consideration. Our team engaged in frequent and ongoing conversations on district selection. Using this data, we selected a diverse sample of 13 districts that varied along a range of dimensions including district type, size, urbanicity, demographics, and designs for elementary science. Our recruitment process extended into the early months of the pandemic and, as a result, was also constrained by districts' bandwidth to be able to participate in a long-term research study.

We selected three districts from the larger sample to present in this report. We identify districts that were (a) representative of the range of dimensions described above from our larger sample of 13 districts, and (b) offered analytically distinct approaches to illustrate a range of system-building efforts districts might engage in to support instructional improvements in elementary science (Table 1).

Table 1: District Demographics

	USD [a]	**SSD**	**CSD**[b]
Total Enrollment (K-12)	> 100,00	> 12,000	> 5,000
Elementary Schools	>100 [c]	≤ 5	≤ 5
African American/Black	7%	7%	93%
Asian/Filipino	15%	13% [d]	0%
American Indian	<1%	6%	0%
Pacific Islander	<1%	-	<1%
White	24%	50%	1%
Hispanic (any Race)	44%	13%	5%
Multiple Races	8%	11%	1%
English Learners	19%	15%	4%
Students w. Disabilities	11%	19%	14%
Socioeconomically Disadvantaged [e]	57%	35%	96%

Note: Race/ethnicity categories vary across states and are synthesized here. School & enrollment counts have been blurred for anonymity.

[a] Data from USD was from the first year of district-level data collection, SY20-21. However, in CSD and SSD, the most up-to-date data available was from SY18-19

[b] CSD demographic data was calculated using individual school data as district-wide data were not publicly available.

[c] This includes Elementary and K-8 schools but not K-12 schools

[d] SSD reports Pacific Islander students in the category Asian & Pacific Islander

[e] Each district's state calculates this in different ways.

Urban School District (USD) is a large public school district serving over 100,000 students, more than 70% of whom are students of color. We focus specifically on a comprehensive, K-5 NGSS-aligned science initiative initially piloted in about one-third of USD's elementary schools. Suburban School District (SSD) serves over 12,000 students, about half of whom are students of color, one-third are socioeconomically disadvantaged, and one-seventh are emergent multilinguals. Charter School District (CSD) is located in a large urban area and serves over 5,000 students (approximately 13% of public-school enrollment in the city), more than 90% of whom are students of color and more than 90% of whom are socioeconomically disadvantaged.

Data Collection

Data collection for this phase of the study took place between 2020 and 2021 and included interviews with central office leaders, observations of district-level routines in science, and collection of district documents pertaining to elementary science (Table 2).

Table 2: Data Collection by District

	USD	SSD	CSD
Interviews	15	12	7
Observations	3	6	2
Documents	20	28	18

In total for this sub-sample, we conducted 34 interviews of central office staff. Interviews were semi-structured (Glesne, 2011) and lasted between 30- and 60-minutes in length. Participating central office leaders included district superintendents; assistant superintendents; directors of special education, student support, curriculum and instruction, and English language development; district data managers; coordinators for science, mathematics, and English language arts; and others. Interviews with central office leaders focused on district priorities, organizational structure, district community, and instruction and instructional improvement in science and other content areas.

Observations were focused on district-level routines for science. For example, in USD and CSD we observed elementary science professional development (PD) provided by the central office to district teachers and leaders. In SSD, we observed district curriculum adoption meetings for elementary science. We identified these observations in cooperation with central office leaders, with the explicit goal of observing routines or sessions coordinated and facilitated by central office leaders in science. Research team members conducted the observations remotely and recorded field notes using an observation protocol along with personal reflections on the observed session (Emerson et al., 1995). We also gathered documents that included sources detailing district demographics and priorities, curriculum materials for use by teachers, district improvement plans, and associated PD materials. Our field notes, as well as organizational documents collected from central office leaders, provided triangulation for emerging themes from our interviews (Miles & Huberman, 1994).

Analysis

The data collection and analysis were integrated, allowing the research team to identify patterns and working hypotheses as they emerged from the data while refining data collection strategies as the study progressed (Miles & Huberman, 1994). We began our analysis by first developing provisional analytic memos (Yin, 2009) for each of our districts that synthesized interview notes, observation field notes, and documents to establish preliminary understandings of how each district engaged in education system-building. All memos were shared and discussed with the research team. We then moved to deductive and inductive coding of the data (Miles et al., 2014) of the data. Using the qualitative analysis software, NVivo (QSR

International Pty Ltd., 2018), we deductively coded our interview data across all 13 case study districts using the analytic framework for system-building presented in this report: that is, system-building as pursued through the work of central offices and schools in managing environmental relationships, building educational infrastructure, supporting the use of infrastructure in practice, managing performance, and developing and distributing leadership.[1]

A team of four coders met weekly for several months to norm our interpretations of the analytic framework as applied to our transcribed data as we worked to develop reliability across coders on interview transcripts.[12] Once we attained a satisfactory agreement of 80% or higher in each domain, we continued to double-code 10% of our interview transcripts in order to monitor ongoing agreement, and we engaged in discussion with one another when disagreements surfaced. We also inductively coded the same set of interview data using a set of preliminary analytic codes (e.g., context, dilemmas, quality, equity, and internal dynamics).

For the purpose of this study, we generated reports of the coded data for each of the system-building domains in three of the case study districts. We then refined and elaborated the analytic memos for each district that described the district's design in each of the system domains and in the preliminary analytic codes. The research team met regularly to discuss developing themes and points of contrast in the district designs. We then developed a comparative analytic matrix that enabled us to better identify patterns and divergence across these districts.

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[1] We will include samples and evidence of our coding scheme in future iterations of this work.

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We continue, then, with case narratives for USD, SSD, and CSD, along with analysis of dilemmas of system-building as playing out in these three districts and in the additional districts in our sample.

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Notes

[1] This argument about a *resource-forward* logic of improvement is developed in detail in an historical analysis of the macro-level policy contexts of US educational innovation and improvement (Peurach, Foster, Lyle, & Seeber, 2022). Our analysis dates the development of the resource-forward logic to the first decades of public schooling in colonial America. It also positions the resource-forward logic as dominant to the present day. For more on the centrality of the resource-forward logic, see Peurach, Cohen, Yurkofsky, and Spillane (2019).

[2] Our use of the 2014 report of the National Science Board is intended to set the stage at the historical moment that the NGSS were released, with a focus on illuminating what we view as formidable gaps among macro-level policy instruments (i.e., standards and teacher certification requirements) and between macro-level policy instruments (standards) and micro-level capabilities (as evidenced by then-current occupational demographics). As an historical document and comprehensive synthesis of then-current policies, occupational demographics, and other relevant statistics (including analyses of the 2012 National Survey of Science and Mathematics Education, NSSME), the 2014 NSB report serves this purpose well. For changes in occupational demographics in the first four years of the NGSS rollout, see the 2018 National Survey of Science and Mathematics Education (NSSME+) report (Banilower et al., 2018).

[3] This conceptualization of "organization" and consideration of the ubiquity of organizations in contemporary society draws from Scott and Davis (2007).

[4] While organizations have existed across societies for all of documented human history, Scott and Davis (2007) date their rise to ubiquity (and their structural evolution from communal to associative) to the 1700s and 1800s, beginning with the Enlightenment into the Industrial Age – in effect, contemporaneous with the rise of mass public schooling. Where Simon (1969) describes organizations as defined here "artificial", Weick (1979), goes further, to describe environments not as objective realities but as subjective realities co-constructed by people. Simon (1969), Weick (1979), and Scott and Davis (2007) are recognized as seminal contributions within the field of organizational studies. Interestingly (at least to us), organizational studies only began to cohere and develop as an interdisciplinary field following World War II – contemporaneous with (but disconnected from) the initial efforts of the federal government, through the National Science Foundation, to support science education reform. We note these matters and references to remind ourselves about (and to sensitize others to) seminal work among organizational scholars that may merit discussion and debate among science education reformers as they conceptualize and theorize relationships among environments, organizations, instruction, and learning. (Our hunch is that much of this discussion and debate will require considering dictionary definitions vs. field-specific conceptualizations of "collective", "artificial", "nature", and "environments".) We note them also to remind ourselves (and others) of the historical recency of the ubiquity of complex organizations and of the field of organizational studies, and of the novelty of bridging organizational studies and science education reform.

[5] To readers of this initial draft: We are open to considering alternatives to “deterministic”. In this turn, we are seeking to establish the structure/agency tension. We are happy with” mutable” as opening opportunity for agency. We are worried that “deterministic” may overstate.

[6] This account of “contemporary complications” and the following account of “legacy complications” draw from two comprehensive historical reviews of the co-evolution of macro-level policy contexts and meso-level instructional organization, management, and improvement in the United States (Peurach, Cohen, Yurkofsky, & Spillane, 2019; Peurach, Foster, Lyle, & Seeber, 2022).

[7] For the emergence of commercial markets supporting ELA and mathematics instruction, see Peurach, Foster, Lyle, & Seeber (2022).

[8] On the origins of “sorting, resourcing, and delegating”, see Peurach, Cohen, Yurkofsky, & Spillane (2019).

[9] As we argue elsewhere, these interacting policy logics were integral to a profound shift in approaches to innovation and improvement being advanced in macro-level policy contexts in the United States, beyond “resource-forward” innovation and improvement to “practice-forward” innovation and improvement (Peurach, Foster, Lyle, & Seeber, 2022).

[10] This analysis of institutional work, its characteristics, and its dilemmas draws from an earlier analysis of field building aimed at democratizing educational innovation and improvement (Peurach & Cohen-Vogel, 2022).

[11] http://sdbjrfoundation.org/education/stem/advancing-teaching-and-learning/ngss-early-implementers/

[12] The coding team included four people who identify as white, middle-class women with high levels of educational and social capital. Because of this composition, care was taken to broaden our perspectives, through ongoing conversation with the broader team and our advisory board. However, we recognize that our positionalities may have limited what we saw and how we saw it in the data.