Pedagogy vs. Reality: An Investigation of Supports and Barriers when Implementing NGSS Storylines

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Abstract

Over the course of a two-year curriculum field test study that implemented a curriculum-based professional learning framework, we investigated the factors that influenced teachers' willingness and ability to implement NGSS-aligned, phenomenon-based storylines for teaching the nature of science, evolution, and climate change. Through qualitative data collected from interviews and lesson evaluation surveys from 25 middle and high school science teachers, we identified potential implementation barriers and support structures relating to organizational culture as well as curriculum and instruction at the classroom, school, community, and systemic levels. The data indicate that lack of administrative support, time constraints, difficulty with student sense-making, and mismatched classrooms are the largest barriers to implementation, while curriculum-based professional learning including working through the lessons from a student perspective, peer collaboration, autonomy, and flexibility were the largest predictors of successful implementation. Administrators can play a large role in providing successful supports and removing barriers for teachers implementing NGSS-aligned, phenomenon-based lessons.

Keywords: curriculum adoption, instructional change, Next Generation Science Standards, phenomenon-based instruction, storylining, professional learning

Introduction

As the expectations for high quality science teaching, learning, and assessment change with the adoption of new standards such as the Next Generation Science Standards (NGSS), there is an increasingly stronger emphasis on the part of researchers to examine the effectiveness of science curriculum and instructional practices. Although coherent phenomenon-based inquiry instruction is one of the most effective teaching strategies available to science teachers, successful NGSS storyline implementation can be challenging for a variety of reasons (Allensworth et al., 2022; Anderson et al., 2018; Cassata & Allensworth, 2021). These challenges include lack of administrator understanding and support regarding NGSS instructional shifts, teacher discomfort with new pedagogical approaches, lack of student proficiency in taking a more active role in their own learning, and perceived time constraints (Allensworth et al., 2022; Anderson et al., 2018; Cassata & Allensworth, 2021). Although high-quality instructional materials can support the development of science knowledge and skills in teachers and students, even when teachers use lessons designed to be aligned to the NGSS, they still may not be engaging students in rigorous thinking about science concepts if they have not been properly trained in the use of these materials and the theory behind their development (Allensworth et al., 2022; Tekkumru-Kisa et al., 2017). This two-year curriculum field test study aims to add to the literature by investigating factors that influence middle and high school teachers' willingness and ability to implement NGSS-aligned, phenomenon-based storylines.

Background

Academic Standards

State education standards have long been known to affect science teaching and learning because they directly prescribe student learning outcomes based on learning progressions for content area and grade level (Cuban, 1995; Harris et al., 2017; Watts et al., 2016). These state standards not only determine which concepts will be taught in particular subject areas but often dictate the depth and scope to which they should be covered, the methods by which they are expected to be taught, and how they will be assessed (Moore, 2002; Watts et al., 2016). This, in turn, determines the level of attention given to these subjects by teachers and administrators, influences the development of high-stakes assessments, and can even impact funding allocation for materials, technology, professional development, and curriculum design (Berkman & Plutzer, 2010; Harris et al., 2017).

In the United States, the role of the federal government in curriculum and instruction is limited. The bulk of educational decisions are made at the state and local levels. Usually, this involves standards adoption and end-of-course assessment decisions being made at the state department level, with some amount of autonomy granted to local school districts to select curricula, textbooks, and instructional materials that fulfill the requirements of the adopted state standards and prepare students for a standards-aligned assessment. Although reform policies and recommendations are often handed down from the national level, sometimes in the form of legislation such as the No Child Left Behind Act and the Every Student Succeeds Act, state and local politics and culture play by far the most significant role in what the standards actually look like for each state (Watts et al., 2016).

The latest attempt at creating a national level set of academic standards for science was the writing of *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* by a committee that included practicing scientists, cognitive scientists, science education researchers, and science education standards and policy experts (National Research Council, 2012). This document laid out crosscutting concepts as well as science and engineering practices that students should understand and be able to perform across all scientific disciplines in addition to disciplinary core ideas specific to each discipline of physical science, earth science, and life science, which form the foundation of knowledge that should be attained by the time a student graduates from high school. The concepts and practices described in the document are arranged both by science content area and across grade bands in order to build a smooth learning progression for students to attain scientific literacy in their K–12 career. On the basis of this *Framework*, a committee of experts from lead state partners created the Next Generation Science Standards (NGSS) and presented them to the states for consideration (Watts et al., 2016).

Since their development and release in 2013, 20 states and the District of Columbia have adopted the NGSS as originally written, while another 25 states have adopted standards based on the NGSS framework with some modifications (Herndon & Andrews, 2023). Both the *Framework* and the NGSS call for a shift toward students figuring out rather than learning about science. Rather than learn to recite facts learned in classrooms and from textbooks, students are expected to demonstrate proficiency in science by engaging in actual scientific practices, reflecting on real world interconnections in science, building conceptual knowledge coherently, and applying deep understanding of the content across many scientific disciplines including life science, earth and space science, physical science, and engineering (National Research Council, 2012).

Storylining

One of the most effective ways for students to gain proficiency in building and applying conceptual knowledge is through an approach called storylining. Storylines are a series of lessons connecting a scientific concept to an engaging phenomenon or socio-scientific issue that cannot be addressed in one classroom session (Reiser et al., 2021). After studying this anchoring phenomenon, students ask questions about it which drive subsequent lessons. Along the way, students use the NGSS science and engineering practices to help answer their initial questions while generating more refined or specific questions along the way. Because students are grappling with questions tied to an anchoring phenomenon, they regularly revisit that phenomenon to add to their explanation or problem solution (Reisner et al., 2021). This coherent, student-driven, inquiry-based process can have significant connections to students' lives and communities, creating personal relevance and practical engagement with the content.

While the NGSS are relatively new in their inception and implementation, studies on the effectiveness of phenomenon-based inquiry instruction more generally have been conducted for more than 20 years. These studies support the efficacy of the storylining approach and formed the research basis of the *Framework*. This form of instruction increases student resilience and perseverance (Abdi, 2014), creativity and innovative problem-solving (Andrini, 2016; Reiser et al., 2021), retention and transferability of concepts (Abdi, 2014; Andrini, 2016; Reiser et al., 2021), proficiency with science and engineering practices (Penuel & Reiser, 2018), science communication skills (Andrini, 2016), and enjoyment of science coursework (Andrini, 2016). These are all admirable qualities in themselves, but additional research investigating depth versus breadth has shown that phenomenon-based inquiry instruction that gives more time and attention to fewer topics increases student outcomes on standardized assessments (Andrini, 2016; Whittington, 2017) and success in college science courses (Sadler & Tai, 2001; Schwartz et al., 2008). Additionally, this style of instruction has also been shown to decrease gender, socio-economic, and racial gaps in performance (Reiser et al., 2021), in addition to student burnout and boredom (Andrini, 2016).

Curriculum Adoption and Adaptation

After the writing and adoption of the *Framework* and NGSS, the next big challenge for states and districts was selecting or developing appropriate curricula to teach the content and skills required in an appropriate way that aligned with the recommendations of these documents (Smith et al., 2022). This was, and continues to be, a monumental challenge, requiring significant time, money, and energy, on the part of both curriculum providers and school districts (Reisner et al., 2021). Recent years have seen an increase in NGSS-aligned curriculum development by both commercial and open educational resource (OER) providers, but owing to the time involved in developing, testing, and training teachers to use these curricula, there is still an extremely high demand for vetted high-quality instructional materials (Smith et al., 2022).

As of the writing of this article, only one year-long elementary school curriculum, Amplify Science, two year-long middle school curricula, OpenSciEd and Amplify Science, and one year-long high school curriculum, BSCS Biology, have been rated as exemplary by the Evaluating the Quality of Instructional Products (EQuIP) rubric for science (EdReports, 2024). Of the approved curricula, OpenSciEd is an OER that is free to use by all teachers and school districts while Amplify Science and BSCS Biology are produced by commercial curriculum providers. Aside from these four curricula, there are no other full course curricula that fully meet the expectations for NGSS-aligned instruction. This means that, in most cases, teachers or districts must evaluate and select resources from multiple sources and assemble them into a coherent curriculum on their own. A national study by Smith and colleagues (2022) demonstrated that this is indeed the case: 62 percent of middle school teachers and 84 percent of high school teachers stated that they routinely used science materials they had created themselves. This is further complicated by the fact that 97 percent of middle school teachers and 99 percent of high school teachers stated that the progress of changing or acquiring adequate instructional materials was either not started, just beginning, or underway with much left still to do (Smith et al., 2022). This shows a significant area of need that has not yet been met, as high-quality instructional materials are one of the key factors necessary for meeting the needs of teachers and students who are attempting to realign instruction to meet these new standards.

Many states, including Louisiana, Maryland, Massachusetts, New Mexico, and Washington, have recently partnered with companies such as WestEd and EdReports to invest significant time and resources into evaluating and identifying high-quality instructional materials for recommendation to their districts for adoption, often with incentives for using approved curricula (Smith et al., 2022). However, even among those teachers using the handful of vetted and approved curricular materials available, many are not meeting the expectations called for by the *Framework* (Allensworth et al., 2022; Cassata & Allensworth, 2021). Educative curriculum materials can support the development of science knowledge and skills in teachers, but only when coupled with professional learning. Teachers must fully understand the theory and rationale of NGSS aligned materials in order to use them appropriately and maintain the intended intellectual and skills-based rigor (Allensworth et al., 2022; Tekkumru-Kisa et al., 2017).

The divergence between what teachers are asked to do and what they in fact do has been demonstrated in many studies over the past few decades. As Cuban (1995) described, there can be significant differences, especially in the early stages of curriculum reform, between the *official* curriculum (state and district curricular frameworks), the *taught* curriculum (the actual subject matter focus and teaching methods used), and the *learned* curriculum (what the students actually take away from a lesson or course of study). Tekkumuru-Kisa and colleagues (2017) noted similar issues with individual tasks within a curriculum, often seeing a divergence among the framework progression of tasks as they appear in curricular materials, tasks as *set up* by the teacher, tasks as *enacted* by the teacher and students, and student learning. These studies, along with others, demonstrate that creating and adopting high-quality instructional materials, while an important initial step of instructional reform, is not a panacea that can replace other measures.

Professional Learning

Evidence suggests that many science teachers have not had sufficient experience or professional training with the content relevant to the courses they teach or the science and engineering practices associated with the NGSS (Banilower, 2019; NASEM, 2015). This is becoming an increasing problem especially among elementary teachers and those teaching out of their field or without appropriate certifications (Ingersoll, 2002; Van Overschelde, 2022). Additionally, because the vision for science education laid out in the *Framework* contrasts significantly with the type of instruction most teachers experienced in their own K–12 education, as part of their university education, and with what is happening in most science classrooms currently, even teachers knowledgeable in science content need ongoing professional learning to understand the NGSS and how to implement them appropriately in their classrooms (NASEM, 2015; Smith et al., 2022). Past research has suggested that there are three important areas in which all science teachers need to develop expertise: (1) knowledge and skills required to support a diverse range of students, (2) content knowledge of the subject matter they are teaching, and (3) pedagogical content knowledge for teaching science (NASEM, 2015).

More specifically, syntheses of best practices for high-quality professional learning for science teachers identify five critical aspects: (1) content focus, (2) active learning, (3) coherence, (4) sufficient duration, and (5) collective participation (NASEM, 2015; Smith et al., 2022). Content focus refers to learning opportunities that focus on subject matter content and how students learn that content. Active learning requires that teachers be active participants rather than passive recipients during the learning process and engage in activities such as observing expert teachers, reviewing student work, and leading discussions about teaching and learning in context. Coherence describes professional learning that is consistent with other experiences as well as with school, district, and state policies. Sufficient duration means that the professional learning experience includes a sufficient number of hours and a sufficient span of time over which those hours are experienced in order to allow repeated practice and reflection. Finally, collective participation suggests that teachers participate with other colleagues from the same school, grade, or department.

Currently, the K–12 science education field lacks a strong plan for adequate professional development opportunities for science teachers. Banilower and colleagues (2018) reported that 63 percent of elementary school teachers, 30 percent of middle school teachers, and 26 percent of high school teachers had received fewer than six hours of professional development related to science in the previous three years combined. The same study suggested that fewer than half of science teachers attended professional learning that allowed them to experience instruction as their students would, and only about one-third reported that their professional learning focused on implementing the instructional materials used in their classrooms.

While there is a clear consensus in the science education community that coherent phenomenon-based inquiry instruction is effective, there is also ample evidence that making this instructional shift from more traditional teaching practices may be a difficult process for everyone involved, including teachers, students, administrators, and parents. This study was guided by the following research question that addresses the problem statement by analyzing the factors that affect instructional change: What factors influence the implementation of curriculum aligned with the NGSS?

Owing to the needs of science teachers and recommendations from syntheses of literature regarding implementation of high-quality professional learning, our study used a curriculum-based professional learning framework. Rather than focusing on teachers' content knowledge, teaching strategies, or theoretical understanding of the NGSS alone, curriculum-based professional learning does all of these in the context of the instructional materials teachers are using (Smith et al., 2022).

Methods

Project Context and Timeline

Curriculum Development

This study began in the summer of 2020, during which the National Center for Science Education (NCSE) began developing lesson sets specifically designed to help teachers address and dispel common misconceptions regarding the nature of science, evolution, and climate change. These lessons were collaboratively developed by NCSE staff along with workgroups of NCSE Teacher Ambassadors, veteran master teachers well-versed in the NGSS from around the country who had experience teaching these topics in a variety of settings to a wide range of students. Each lesson set consists of five individual lesson storylines that each target specific student misconceptions such as "science is complete, absolute, and unchanging," "evolution results in a linear progression toward an ultimate goal," and "there is no scientific consensus on anthropogenic climate change."

Using the framework of Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge model to guide the approach to overturning student misconceptions, the workgroups started with a list of common student misconceptions around each of the three topics. Then, they linked each misconception with a corresponding standard from the NGSS that addresses content relating to the misconception. Next, the workgroups chose an engaging, relevant anchoring phenomenon or engaging hook for each lesson that would allow students to generate questions. They then developed activities to guide the students through the exploration of authentic data using science and engineering practices associated with the NGSS to learn more about the scientific concepts that could help them answer their driving questions to explain the phenomenon. Formative assessments were embedded in the activities in order to gauge students' progress with regard to the content, science and engineering practices, and correction of misconceptions.

The individual Teacher Ambassadors field-tested the lessons in their own classrooms to ensure coherence and usability. The workgroups then reconvened to provide feedback and make recommendations and adjustments based on their classroom experiences using the lessons. Next, NCSE curriculum developers used the lesson plan outlines and feedback to create consistent teacher guides, student activity sheets, and activity materials that were then loaded into a public Google Drive for all teachers to access.

Field Study Recruitment and Sample Selection

After the lessons had been written, tested, and adjusted to a consistent format by the Teacher Ambassadors and curriculum developers at NCSE, the next step was to test lesson efficacy with teachers and students who were not involved in their development. Stage 1 included the recruitment of Curriculum Field Testers (CFTs) in March 2021. Thirty-two teachers from 21 states were selected from a pool of 99 applicants based on factors such as their familiarity and experience with the NGSS, their familiarity and experience with inquiry-driven teaching, the degree of curricular autonomy they were allowed by their school or district, administrative support to participate, and their willingness to commit to fully implementing the lessons. These teachers included eight middle school teachers and 24 high school teachers whose primary teaching areas were life science, biology, Earth science, or environmental science. Twenty of the participating CFTs were the only science teachers in their school who participated in the program, while the remaining 12 were from one of four schools whose science department chose to participate in the program collectively. The sample included eight white males, 21 white females, and three African American females. These teachers ranged in experience from three to 35 years in the classroom.

After being selected for the program, CFTs were assigned to one of two cohorts, evolution or climate change, depending upon which topic aligned with the primary courses they would be teaching in the upcoming school year. Each cohort was then broken into three peer support groups of five to six teachers and assigned a mentor from the existing Teacher Ambassador group who specialized in that content area and had participated in the development of the lesson sets. These peer groups, led by the mentors, would serve as an intimate professional learning community that, in addition to the larger network of CFTs, Teacher Ambassadors, and NCSE Supporting Teachers staff members, provided assistance, suggestions, and feedback throughout the two-year program.

Before the official start of the program, however, two teachers removed themselves from participation, and another five participants had to leave the program before the end of the first year due to changes in teaching assignments, other professional obligations, or time commitments. This left the program with a sample of 25 participants who were available to participate fully and one participant who was able to contribute partial data for the first year. During the second year, three new CFTs were recruited from schools that already had a partner participating in the program.

Initial and Sustained Professional Learning

During Stage 2 of the program, the CFTs attended their initial two-week long training in July and August of 2021. Due to ongoing COVID-19 restrictions, this professional learning academy was held virtually through a series of Zoom meetings and consisted of professional learning regarding the NGSS, the theory and practice of storylining (coherent, phenomenon-based inquiry instruction), an introduction to the misconception-based approach to science teaching, instructions on how to navigate and use the curricular materials, an overview of the NCSE storylines and lessons, and opportunities to participate in the lessons from the student perspective.

During Stage 3 of the program, CFTs participated in sustained professional learning, which consisted of monthly Zoom meetings throughout the program (four each semester) in which the NCSE Supporting Teachers staff, taking guidance from literature detailing best practices in professional learning (NASEM, 2015; Penuel et al., 2011; Smith et al., 2022), provided updates and refreshers pertaining to specific lessons. Furthermore, guest speakers discussed relevant research in the fields of climate science, evolutionary biology, and resolving conflicts in the classroom regarding socially controversial topics. During these monthly meetings, CFTs also had the opportunity to participate in breakout rooms with their peer support groups and mentors to provide progress updates and feedback on lessons they had completed, discuss upcoming lessons, and suggest modifications to the lessons for students with diverse learning needs.

Between monthly meetings, peer group mentors would check in with their CFT group members via email, text, or video chat as needed to provide support and feedback about lessons. CFTs also had the opportunity to reach out to other members of their peer support group, mentors, or the NCSE Supporting Teachers staff as needed for assistance with curricular or pedagogical concerns. Finally, in order to provide a space for a larger and more informal community of practice, the NCSE staff also created a private social media group where CFTs and Teacher Ambassadors could share materials, ideas, ask questions, and provide additional support and advice. This social media space also gave participants a platform to have broader discussions about how to communicate with students, parents, and administrators about misconceptions and socially controversial science topics as well as share ideas about science, curriculum, and professional learning opportunities to help strengthen the participants' self-efficacy and identities as engaged science educators (Kelley et al., 2020).

During Stage 4 of the program, CFTs were all brought together face-to-face for the first time after completing the first full year of the field study in July 2022 for a week-long professional learning academy. This academy consisted of CFTs reflecting upon and sharing their experiences with the curricular materials, reviewing adjustments that had been made to the curricular materials based on the feedback and suggestions from the CFTs throughout the first year of implementation, opportunities to rehearse these modifications from the student perspective, field trips to engage in science practices and place-based learning, and discussions about science education leadership in their communities. In addition to providing opportunities for reflection, modifications, and practice, another goal for the academy was to re-engage the participants in a community of practice and build their capacity and efficacy as science teacher leaders in their local spaces (Kelley et al., 2020).

At the conclusion of the second year of the study, participants completed Stage 5 of the program, the capstone. For their capstone projects, the CFTs were asked to provide three artifacts: a realistic pacing guide for one of the three lesson sets based on their experiences with them the prior two years, an overall program reflection regarding the curricular materials and the supports and barriers experienced during implementation, and a lesson plan detailing an extension activity or modification for diverse learners. Refer to Table 1 for a summary of the stages, activities, and outputs of this study.

Table 1

Curriculum Field Study Logic Model and Timeline

Stage	Time Implemented	Activities	Outputs
1	Spring 2021	Recruit CFTs	2 CFT cohorts
2	Summer 2021	2-week virtual initial professional learning academy	CFTs with the knowledge and capacity to implement the NCSE curriculum
3	Summer 2021 – Summer 2023	Sustained professional learning and community of practice	CFTs with the support and efficacy to implement the NCSE curriculum
4	Summer 2022	1-week in-person mid-program professional learning academy	CFTs with the knowledge, capacity, and efficacy to implement the NCSE curriculum
5	Summer 2023	Capstone	Lesson extensions and/or modifications for diverse learners

Data Collection and Analysis

Throughout the program, data from many sources were collected in an attempt to evaluate the effectiveness of the NCSE curricular materials, professional learning, and community of practice. Qualitative data was collected in the form of pre-, mid-, and post-program interviews with each of the participating CFTs, open-ended questions on lesson evaluations, and informal feedback from the participants. Pre-, mid-, and post-program interviews were conducted in the summers of 2021, 2022, and 2023 respectively and consisted of open-ended questions regarding participants’ experiences with professional development and with collaboration, classroom experiences with socially controversial science topics, and expected or experienced supports and barriers to implementing the NCSE curricular materials. These included questions such as the following: How did you implement the NCSE curriculum into your professional practice last year? What roadblocks or barriers did you experience when attempting to implement the NCSE curriculum? What support would have made your experiences easier or more effective? What experiences did you navigate with student misconceptions in your classroom? How did you manage “controversial” topics with students?

Surveys for lesson evaluations included a combination of qualitative and quantitative questions about lesson implementation, fidelity to the curricular materials, activities in each lesson that were completed or skipped, and modifications or supplemental activities added to the lesson. These included questions such as the following: State which parts of the lessons or activities you implemented in your classroom. For each, did you implement them with fidelity, with some modifications, or with major modifications? If you excluded an activity, did you do so because of lack of time, misalignment with your standards, or some other reason and please explain. If you modified a lesson or activity, please explain how you changed it to fit the needs of your students. What activity or activities worked best for your students in this lesson and explain why. What activity or activities did not work well for your students and explain why. Informal feedback was also recorded any time a CFT requested support or assistance from an NCSE mentor or staff member.

As part of the memorandum of understanding (MOU) signed by participants, each CFT was required to participate in three half-hour interviews, attend at least 75 percent of the monthly meetings for sustained professional learning, implement at least 80 percent of the nature of science lesson set and at least 80 percent of either the evolution or climate change lesson set depending upon their cohort, and complete lesson evaluations for each lesson in the sets assigned to their cohort. Additionally, the participants were required to administer a pre-survey and post-survey assessing their students' understandings and misconceptions of related concepts before and after implementing the corresponding lesson set and send the anonymized data to the NCSE staff.

While data collection was still underway at the end of the first year of the program, it became clear that many of the participants were not fully and/or appropriately implementing the curriculum as it was intended. The analysis presented in this paper, therefore, arose as an artifact of the larger study to attempt to understand what supports and barriers caused the participating teachers to implement the curriculum with fidelity or not. To ascertain this, qualitative thematic analysis of the data from the pre-, mid-, and post-interviews as well as open-ended questions from the teacher lesson evaluations were conducted beginning with provisional exploratory codes as described by Saldaña (2021). The initial provisional codes were generated from a review of the literature regarding NGSS implementation and instructional change. After a first pass by the lead author, the codes were adjusted, and coding, categorization, and theming was agreed upon by the authors once unanimous agreement was reached.

Findings

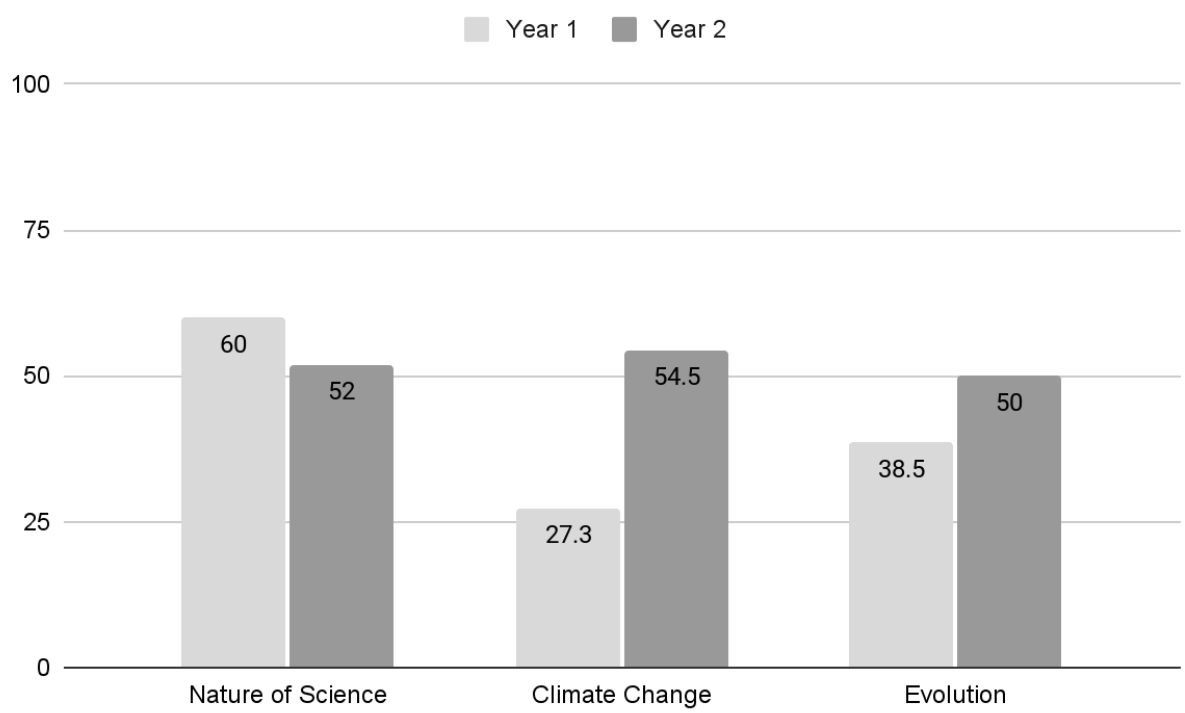
Although all of the participants confirmed that they had approval to participate in the program by their administrators and agreed to implement at least 80 percent, or four out of five, of the nature of science lesson sets and either the evolution or climate change lesson sets in their classroom, participation after the first year was found to be very low. In the first year, only 60 percent of the participating CFTs reported implementing at least 80 percent of the nature of science lessons (Figure 1). Implementation was even lower for climate change (27.3 percent) and evolution (38.5 percent). These low implementation rates caused the NCSE staff to re-evaluate the support structures in place as well as to pivot to investigating what factors were encouraging or discouraging teachers from implementing the curriculum in their classrooms.

In the second year, only 52 percent of the participating CFTs reported implementing at least 80 percent of the nature of science lessons, a decrease from the first year. However, climate change (54.5 percent) and evolution (50 percent) both saw increased implementation of at least four of the five lessons. This was a decrease of 8 percentage points for adequate nature of science implementation, but an increase of 27.2 percentage points for climate change and 11.5 percentage points for evolution.

Through a deeper analysis of the mid- and post-program interview questions as well as the open-ended questions on the lesson evaluations, provisional exploratory codes were generated to understand patterns of supports and barriers to implementation. Table 2 outlines the codes, categories, and themes that emerged from these data, which will be more thoroughly explained below.

Figure 1

Percent of Teachers Completing at Least 80% of Lesson Sets



Explanation of Themes and Categories

During the first pass of coding, two major themes began to emerge as codes were generated, refined, and grouped. The first theme, which was labeled *organizational culture,* consisted of codes relating to auxiliary features, qualities, and interactions outside of the curriculum, including behaviors, attitudes, expectations, and policies of the participants' school, community, or larger educational system. The second theme consisted of codes relating directly to qualities and features of the curricular materials, the instructional strategies embedded in the curriculum, and the outcomes of the curriculum. This theme was labeled *curriculum and instruction*.

Furthermore, the codes within each theme fell within the two major categories of *supports* and *barriers*. The *supports* category contains features and qualities of both the *organizational culture* and the *curriculum and instruction* that encouraged and supported adequate and appropriate implementation of the curriculum. The *barriers* category contains real and perceived barriers that inhibited the participants from adequately or appropriately implementing the curriculum.

Table 2

Organization of Themes, Categories, and Codes

Organizational Culture		Curriculum and Instruction	
Supports	**Barriers**	**Supports**	**Barriers**
Administrative Support (2, 4)	Administrative Support (2, 4)	Student Engagement (1)	Time Constraints (1, 2, 4)
Peer Collaboration (2, 4)	Isolation (2, 4)	Student Achievement (1, 2, 4)	Sense-making (1, 2, 4)
Mentors (2, 4)	Stakeholder Expectations (1, 3)	Science Immersion Model (1)	Transferability (1, 2, 4)
Professional Learning (2, 4)	Mismatched Classrooms (1, 2, 3, 4)	Lesson Flexibility (1, 2)	Content (1, 2, 3, 4)
Autonomy (2)	Absences (1, 2, 3)		
Potential source of support/barrier: 1 = Classroom; 2 = School; 3 = Community; 4 = Systemic			

Data collected also indicated that these supports and barriers came from four possible levels of interactions with the participants. The *classroom* level (1) consisted of interactions within an individual classroom setting involving a teacher and his or her knowledge, understanding, and attitudes toward the curriculum and instructional strategies, the students, and the implementation of the curricular materials. The *school* level (2) included interactions within the local school between the participant and other faculty, administrators, students, and the school culture and priorities. The *community* level (3) consisted of interactions among the participants and all possible stakeholders in the community, including the school and district staff, administrators, students, parents, other community members, and the culture of the community at large. The final level of interaction was the *systemic* level (4). This included interactions and influences of the entire K–12 science education community, state standards, state and federal policies and resources, outside curriculum and professional development organizations, as well as the general attitude toward science education in the state or country.

Analysis of Codes

Organizational Culture: Supports

Administrative Support. Participants stated that having administrators at their school and/or in their district who understood the state standards and the expected instructional shifts of the *Framework* were a large positive source of support for instructional change and the implementation of an NGSS aligned curriculum. Other manifestations of administrative support included encouragement and assistance of the teachers in seeking out tools and professional development to aid in their implementation of these instructional shifts, including approving leave to attend professional development or conferences, securing substitute teachers, and providing funds for travel and registration if necessary. Also included in administrative support was the perception on the part of participants that their administrators would speak on their behalf to other stakeholders, including parents and district administrators, regarding the instructional decisions made by the teacher.

Peer Collaboration. Participants shared that having peers at their school who were also piloting the same curriculum provided a large incentive for them to implement the lessons. J.N., whose whole middle school team participated in the study, explained, “I feel lucky that my co-teachers from my school were able to do this program with me as a team. Not only was it easy to plan lessons and troubleshoot together, but we also held each other accountable for following through with the lessons and the program.” These peers assisted both through direct co-planning, troubleshooting, and feedback as well as serving as an accountability motivator in the school. Another member of that team, M.E.M., commented:

> This community of practice really encouraged me to try new lessons and change my teaching style. I had lots of productive conversations with the other two collaborators at my school that we probably wouldn’t have had otherwise. It also made me feel that what

I am teaching is important and that my efforts to teach difficult topics thoroughly and accurately are worth it and that I am not alone in my efforts.

Other participants who did not have a colleague participating from the same school stated that their peer support group was a useful tool despite not meeting frequently or in person, especially if members of their group were teaching the same courses or at the same grade level. C.M. stated, "I don't often get to collaborate with colleagues in a meaningful way that leads to student success, so being part of this program and communicating with fantastic teachers from all over the country has been amazing." Participants mentioned that the benefits included sharing how lessons worked or did not work effectively, modifications or adjustments made for diverse learners, and pacing and preparation expectations.

Mentors. Participants stated that having access to a mentor who was knowledgeable about the standards, curriculum, and pedagogical strategies that could provide advice and feedback was a key to their successful implementation. This included both in-person, school-based mentors, such as instructional leaders and department heads, as well as the Teacher Ambassador mentors for their peer support groups. A.G., who did not have a science instructional leader at their school stated, "[My Teacher Ambassador mentor] was great. Any time I had a question or wanted to run through a lesson before teaching it, he was available to walk me through it."

Professional Learning. Some participants, especially those who did not have experience with NGSS storylines, stated that they benefited from the initial and ongoing professional learning regarding this style of curriculum and instruction. Participants who were experienced in this style of instruction mentioned instances of prior professional learning which had increased their understanding and confidence in the NGSS or phenomenon-based instruction. Key aspects of the professional learning that supported implementation were an understanding of the three dimensions of the NGSS, how the three dimensions are woven into each lesson, how to use the anchoring phenomena to guide student learning, and how to use the driving question board and other formative questioning techniques to assess student understanding of the phenomena and the concepts and skills of the standards.

Autonomy. Participants who expressed that their school or district administrators allowed for curricular autonomy demonstrated higher levels of engagement and implementation of the curriculum during the study. M.L. noted that, "My [administrators don't] have a science background, but they have always been really supportive of me trying new things that engage the students. As long as I give them a heads-up and let them know what we will be doing, I know that they'll have my back if something comes up with a parent or student concern." These teachers often mentioned that their administrators or district supervisors did not mandate the use of a particular set of curricular materials or an overly structured script or pacing guide.

Organizational Culture: Barriers

Administrative Support. Participants who had administrators who were unfamiliar with, or unsupportive of, the NGSS and curricular and instructional shifts related to the *Framework* were less likely to be motivated to implement the NCSE curriculum. While there were not any instances of participants who reported that their administrators were vocally against its use, some participants relayed that their administrators did not have a working knowledge of the standards or the expected instructional changes encouraged by the *Framework*. Other participants also stated that they were not given time or funding to pursue professional development opportunities related to science curriculum and were therefore expected to seek out professional development opportunities on their own time and pay for it themselves. It was also mentioned by some participants that they did not feel that their administrators would support their instructional decisions if challenged by students or parents.

Isolation. Teachers who were the only participants in the study from their schools more frequently reported feeling more isolated during the field test. This could have led to a lack of motivation to fully and appropriately implement the curriculum owing to a lack of confidence or lack of accountability. Additionally, some participants reported that not only were they the only teachers at their school participating in the NCSE field study specifically, but also the only teachers in their schools attempting to implement phenomenon-based inquiry in general. These participants felt that there was a general attitude among their colleagues that there was no need to change the status quo, which could have led to a lack of motivation to innovate and try new methods on their part. Another finding was that teachers who did not participate in the NCSE peer support groups or communicate frequently with their Teacher Ambassador mentors were less likely to implement the curriculum.

Stakeholder Expectations. Both active and inactive participants reported issues with stakeholder expectations. These issues included complaints from students about the increased shift to student-centered learning called for by the *Framework* as well as parent concerns about how to assist their children during the learning process. For instance, students who had not experienced NGSS-aligned instruction in previous classes often struggled with the sense-making activities incorporated in the curricular materials. Parents also expressed complaints such as the lack of notes, study guides, and textbooks. Aside from generating feelings of frustration by teachers, students, and parents, these concerns also led some teachers to modify instruction in ways that decreased the rigor of the curriculum or to shift away from three-dimensional instruction to instruction focused more heavily on content.

Mismatched Classrooms. Participants who did not implement the curriculum fully or appropriately frequently made comments indicating that there were one or more issues causing a mismatched classroom situation. Mismatched classrooms occur when the norms, purpose, or obligations of the teachers, administrators, or other stakeholders do not align with those of NGSS-aligned teaching and learning. These comments cited conflicts between teachers' expectations of appropriate rigor and the rigor called for by the *Framework,* conflict between the administrators' priorities or expectations for academics and the priorities of the standards, conflict between the state standards and the state end-of-course assessment or accountability measure, and conflict between students' expectations or goals and those of the teacher and/or standards. K.J., who taught high school biology, noted, "There really isn't any advantage for me or my students to go all in with storylining since the state test is not three-dimensional. The questions [on the state assessment] are simple recall about content." Another participant stated something similar, relating that their administrator wanted there to be more focus on preparation for the ACT (a standardized college admission test) owing to the fact that the ACT was factored into the school accountability score, not a standardized test for that particular content area.

Absences. Both active and inactive participants reported conflict and confusion dealing with absences. Because of the necessity of having students engage with the storyline, teachers expressed frustration with finding solutions whenever they or their students were absent. Participants mentioned that the storyline process was too complex to trust to a substitute whenever they had to miss work for various reasons. Also, some teachers reported not knowing how to appropriately engage the students who missed one or more lessons with the science and engineering practices they should have engaged with in the classroom. Teachers either had to stay after hours to perform make-up lessons with the students or resort to providing only the missed content.

Curriculum and Instruction: Supports

Student Engagement. Teachers who successfully implemented the curriculum frequently mentioned that their students demonstrated a high level of engagement with and enjoyment of the phenomena and activities during the lessons. This student engagement with the lessons seemed to create a positive feedback loop, which encouraged the teachers to continue implementing more of the lessons in the lesson set. A.S., when discussing a particular evolution lesson set, explained that, “The anchor really caught most students’ attention as they imagined a cat-sized horse. They were immediately engaged in thinking about how and why the size of horses could have changed over time and wanted to come back the next day to figure it out.”

Teachers familiar with other NGSS-aligned curriculum also preferred the shorter self-contained storylines of the NCSE designed curriculum. K.F., who had previously implemented storylines from another curriculum developer, explained:

> These mini storylines that only take a week or two before moving onto another lesson with a new phenomenon work so much better for my students than the longer storylines that can take six or sometimes eight weeks. My students get tired talking about the same phenomenon over and over again for more than a month. I get tired of it, too, to be honest. These [shorter storylines] hold their attention, teach the concept, and then move on to something new.

Student Achievement. Similar to student engagement, participants who implemented the lessons reported feeling motivated to continue with more lessons after seeing an increase in student proficiency on NGSS-aligned formative assessments. Participants mentioned that because the students were given multiple opportunities to practice skills such as reading, modeling, and constructing arguments from evidence, the students became more proficient and confident in their ability to demonstrate the science and engineering practices of the NGSS. M.L., who taught a science and society class, stated:

> As they progressed [through the lessons], they got better and better at pointing out things that were examples of pseudoscience or things that don’t line up quite right with what the data is showing, not only in content they came across, but also in their personal lives and on social media…It was very interesting watching that progression and watching them learning and using those tools.

Science Immersion Model. Participants described how having the opportunity to practice the lessons from the student perspective during the professional learning academy and monthly online meetings allowed them to understand how the lessons were supposed to be implemented. They also mentioned that this student perspective gave them foresight into potential barriers and questions that their students might generate. This foresight allowed the teachers to plan in advance how to scaffold the lesson to help students overcome expected barriers and prepare responses to predicted student questions. A.S. noted, "This summer [2022] was great! Last year, I was struggling a little with how these lessons should look and what to do with my students, but getting the chance to actually do the lesson myself with a student hat on gave me a better feel for how it flows and now I know what to look out for."

Lesson Flexibility. Teachers commented that having flexibility to teach lessons in different orders or individually, and not as an entire unit, allowed them to incorporate the curriculum into their classrooms more easily. Because each lesson within a unit has its own unique anchoring phenomenon instead of a single phenomenon for the entire unit, teachers had the flexibility to weave the NCSE curricular materials throughout their course or use them to supplement a curriculum that was already being used by their school or district. Other teachers also mentioned that being able to teach a complete lesson with a unique phenomenon in a shorter time frame allowed them to still use the NCSE materials even though their school or district did not allot a large enough portion of time to teach the entire unit. M.L. said, "I never had enough time to fully implement all aspects of every unit. However, because each lesson had its own small, self-contained storyline, it still made sense and I didn't feel that anything was lost if we only got through two or three lessons instead of all five."

Teachers also commented that having multiple variations for most activities was helpful. Most of the activities included in the curricular materials contain high-tech and low-tech variations as well as options for physical 3-D printed materials (e.g., accurate replicas of fossil horse teeth) when appropriate. This allowed teachers with access to 3-D printers to fully maximize the hands-on aspects of the activities, but did not exclude teachers without this access since they could use computer-based versions or printed versions of the materials to fit their specific needs. J.S. noted, "I don't have a 3-D printer, so I couldn't have them measure the physical models, but we were still able to do the lesson using the card sets. I'm glad that that option was available because I really wanted my kids to experience this activity."

Curriculum and Instruction: Barriers

Time Constraints. One of the most frequent responses from teachers who did not fully or appropriately implement the lesson sets was a lack of time. Many participants reported that their school or district pacing guidelines did not allot enough time for the evolution or climate change standards to teach the NCSE curriculum sets fully. A.G. stated, "I only had time to do one of the [evolution] lessons because my district only has a week and a half slotted out in the pacing guide for evolution." Others commented that because their pacing did not dedicate any time for nature of science instruction, they had to severely limit what they could include from that lesson set and/or find opportunities to incorporate those lessons into other units in their curriculum. Still other teachers reported that although their districts devoted ample time for evolution or climate change, owing to other issues such as days missed for testing, extracurricular activities, or other units taking longer than expected, they simply ran out of time to cover the lesson sets fully.

Sense-making. As already mentioned in the *stakeholder expectations* and *mismatched classrooms* codes, one barrier that was mentioned by participants who struggled with implementation was student sense-making. Owing to the recent adoption of NGSS in some states and the lack of attention paid to science education in many elementary school settings, some participants reported that their students were not used to student-driven instruction and sense-making. D.F., a high school teacher, stated:

> My students just really aren't prepared to do a lot of the activities that are supposed to be student-led. They have a hard time coming up with thoughtful questions for the driving question boards even when I provide prompts for them. It's frustrating for them and me because they don't want to do the thinking; they just want me to tell them what they are supposed to know for the test.

For some students and some teachers, this was their first experience with generating relevant questions to drive their own learning and creating models and explanations to summarize their understanding of a concept. This led to frustration from both the teachers and the students. Some teachers learned how to model and scaffold this sense-making process for students, while others reduced the rigor of the process, which led to the removal of student agency and detracted from the three-dimensional intent of the lessons.

Transferability. Some participants demonstrated their lack of understanding of the theory behind implementing phenomenon-based storylines by making comments that implied that their students were overly engaged with the phenomenon to the detriment of their conceptual understanding of the standards. These comments suggest that the teachers may not have focused on the skills and concepts in a way that would allow their students to transfer conceptual understanding to other phenomena or situations outside of the lessons' anchoring phenomena.

Content. Some participants reported feeling uncomfortable teaching a few of the lessons due to various reasons. A few of the teachers expressed not feeling prepared to teach the lesson on human evolution owing to a lack of background knowledge on their part or the climate change lessons that required mathematical skills that the teachers lacked. "It took me a lot of time and work to figure out the math involved with the precipitation activity. If [my NCSE mentor] wouldn't have been there to walk me through it, I would have just skipped that one," said M.M. Additionally, some teachers mentioned that they expected stakeholder conflict from students, administrators, or parents if they would teach a particular lesson. A.S. stated:

> I had some trouble with getting a set of skulls for the hominid lesson. I wanted to apply for a grant to buy a set, but my principal asked a lot of questions about why it was necessary and if I couldn't teach evolution using a different example. He finally let me apply for the grant after I clearly explained what standards this lesson would address and how I could get the students engaged in it. Even after that, I felt that he still wasn't totally on board with me teaching specifically about human evolution.

Summary of Findings

Participants in the study reported both supports and barriers related to organizational culture and to the curriculum and instruction. From an organizational perspective, teachers who felt supported by their administrators and their fellow teachers and were given the autonomy to try new and innovative practices were more likely to successfully implement the lessons. Working with mentors or team teachers also reduced the feelings of isolation and increased confidence in their ability to persevere. Mismatched classrooms were one of the largest and most complex barriers to implementation as the mismatch can arise at many different levels, from teacher or administrator philosophies or expectations all the way up to having standardized tests that do not truly align to the expectations of NGSS instruction.

In terms of curriculum and instruction, time constraints and student sense-making ability were the largest barriers to implementing NGSS-aligned storylines. These barriers were most commonly countered by teachers experiencing the lessons from the students' perspective during professional development and learning how the lessons could be used flexibly and effectively to fit within their pacing to cover the relevant standards. Teachers also felt more efficacious when seeing the high engagement and achievement of their students when using the shorter storylines that focused on student skill acquisition. Teachers mentioned that shorter, flexible storylines prevented "phenomenon fatigue" and allowed teachers to become more comfortable using research-supported practices.

Discussion

Throughout a sustained two-year curriculum-based professional learning program, we attempted to understand the supports and barriers that affected teachers' willingness and ability to adopt and implement phenomenon-based inquiry driven lessons aligning to the NGSS. Teachers participating in the program demonstrated more knowledge and comfort with the materials in the second year of the program and were better able to effectively implement the curriculum to meet the needs of their unique situations.

Through qualitative thematic analysis of the data from the pre-, mid-, and post-interviews as well as open ended questions from the teacher lesson evaluations, it was found that a variety of variables factored into whether, and how effectively, teachers were able and willing to implement the curriculum. Data collected in this study indicated that supports and barriers could arise from numerous interactions within the classroom, the school, the community, or the larger state or national level. Supports and barriers were also present in both themes. Support structures relating to organizational culture included administrative support, positive peer collaboration, access to knowledgeable mentors, effective and sustained professional learning, and increased autonomy. Organizational culture barriers included lack of administrative support, peer collaboration that was absent or negative, conflicting stakeholder expectations, mismatched classrooms, and excessive absences from students or teachers. Support structures relating to curriculum and instruction included higher student engagement and student achievement, professional learning about the curriculum that included a science immersion model, and the flexibility of the NCSE lessons. Curriculum and instruction barriers included time constraints, lack of sense-making skills on the part of the students, ability to transfer knowledge and skills from one phenomenon to another, and lack of content knowledge or comfort on the part of the teachers.

Many of the results that emerged in this study have been corroborated by prior research in related studies. For example, mismatched classrooms, difficulties in student sense-making, and ability to transfer knowledge to unfamiliar contexts have been documented in studies investigating the implementation of three-dimensional lessons (Allensworth et al., 2022; Anderson et al., 2018). Additionally, Birdon (2023) found that teacher flexibility was vital in ensuring effective differentiated instruction, especially when an adopted standardized curriculum was being used. The value of effective, sustained professional development that includes an immersion model from which teachers can experience the lessons from the students' perspective has also been shown to be a crucial component of support (Short & Hirsh, 2022; Smith et al., 2023). Furthermore, Cassata and Allensworth (2021) found that collaborative planning time with colleagues was a crucial component for supporting instructional change aligned with new standards.

Recommendations

NGSS aligned teaching and learning is challenging for all stakeholders involved. Complete systemic realignment will take time. Studies of past instructional change associated with new standards and policy adoptions indicate that affecting significant changes in curriculum, instruction, assessment, professional learning, and preservice teacher preparation may take a decade or more (Smith et al., 2022). Many states are still in the early stages of this newest transition.

While high-quality instructional materials are important, teachers need continual professional learning in order to change their pedagogical practice. This professional learning should be rooted in developing a deep understanding of the content and the NGSS through curriculum that will be used in the classroom. This professional learning should align with the broader goals of the teachers' local policies and expectations as well as provide experience understanding and practicing the curriculum from the student perspective. Teachers also would benefit from supportive mentors and instructional leaders who are experts in the NGSS and the instructional practices aligned with the *Framework* and have experience using the curriculum that the teachers will be implementing. Collaboration with colleagues, both in their own schools and with teachers in a wider network who are teaching the same content, is an essential component in providing support and motivation for science teachers implementing these instructional shifts.

In order to implement the NGSS and the instructional shifts expected by the *Framework*, it is necessary also to provide appropriate professional learning to administrators. In addition to possessing a working knowledge of science standards and teaching practices, administrators should also provide support, encouragement, and advocacy in all aspects of teaching and professional growth to their science teachers. This includes advocating or appropriate teaching decisions to students and parents, providing time, funding, and encouragement for teachers to attend conferences and professional development, and allowing for curricular autonomy. Autonomy must be given to knowledgeable teachers to adopt and adapt curricula in ways that best meet the needs of their specific student population while still maintaining alignment with the NGSS. Administrators who hold their teachers to a strict pacing guide or expect the curriculum to be used as a script are doing so against the recommendations of the consensus of researchers and curriculum producers (Birdon, 2023; Fitz & Nikolaidis, 2020; Mehalik et al., 2008). However, accountability is necessary, since teachers who have perceived barriers or lack the desire or capacity to change their practices still need to be held to the same expectation of rigor for the benefit of their students.

Furthermore, all stakeholders involved should be familiarized with the instructional shifts expected in modern science classrooms. Teachers and administrators need to inform parents as to what high quality science curriculum and instruction looks like and to educate them about the benefits of these modern instructional shifts, which they have probably not experienced first-hand. Similarly, students need to experience a consistent set of scaffolds and models throughout their K–12 educational experience in order to adapt to the new sense-making expectations of the NGSS.

Finally, systemic steps still need to be taken to align teacher and student evaluations, including observation rubrics and state mandated standardized assessments, to the instructional and learning expectations of the NGSS. Without these realignments, there will continue to be mismatched classrooms in which the assessment of teachers, students, and schools do not match the expectations of the NGSS.

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