Journal of Science Teacher Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uste20

Developing Research-Based Instructional Materials to Support Large-Scale Transformation of Science Teaching and Learning: The Approach of the OpenSciEd Middle School Program

Daniel C. Edelson, Brian J. Reiser, Katherine L. McNeill, Audrey Mohan, Michael Novak, Lindsey Mohan, Renee Affolter, Tara A. W. McGill, Zoë E. Buck Bracey, Jamie Deutch Noll, Susan M. Kowalski, Dawn Novak, Abraham S. Lo, Carolyn Landel, Andrew Krumm, William R. Penuel, Katie Van Horne, María González-Howard & Enrique Suárez

To cite this article: Daniel C. Edelson, Brian J. Reiser, Katherine L. McNeill, Audrey Mohan, Michael Novak, Lindsey Mohan, Renee Affolter, Tara A. W. McGill, Zoë E. Buck Bracey, Jamie Deutch Noll, Susan M. Kowalski, Dawn Novak, Abraham S. Lo, Carolyn Landel, Andrew Krumm, William R. Penuel, Katie Van Horne, María González-Howard & Enrique Suárez (2021) Developing Research-Based Instructional Materials to Support Large-Scale Transformation of Science Teaching and Learning: The Approach of the OpenSciEd Middle School Program, Journal of Science Teacher Education, 32:7, 780-804, DOI: 10.1080/1046560X.2021.1877457

To link to this article: https://doi.org/10.1080/1046560X.2021.1877457

Published online: 24 Sep 2021.

JOURNAL OF SCIENCE TEACHER EDUCATION
2021, VOL. 32, NO. 7, 780–804
https://doi.org/10.1080/1046560X.2021.1877457

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Developing Research-Based Instructional Materials to Support Large-Scale Transformation of Science Teaching and Learning: The Approach of the OpenSciEd Middle School Program

Daniel C. Edelson[a], Brian J. Reiser[b], Katherine L. McNeill[c], Audrey Mohan[a], Michael Novak[b], Lindsey Mohan[a], Renee Affolter[c], Tara A. W. McGill[b], Zoë E. Buck Bracey[a], Jamie Deutch Noll[b], Susan M. Kowalski[a], Dawn Novak[a], Abraham S. Lo[a], Carolyn Landel[d], Andrew Krumm[e], William R. Penuel[f], Katie Van Horne[g], María González-Howard[h], and Enrique Suárez[i]

[a]BSCS Science Learning, Colorado Springs, Colorado, USA; [b]School of Education and Social Policy, Northwestern University, Evanston, Illinois, USA; [c]Boston College, Boston, Massachusetts, USA; [d]Charles A. Dana Center, University of Texas, Austin, Texas, USA; [e]University of Michigan, Ann Arbor, Michigan, USA; [f]University of Colorado, Boulder, Colorado, USA; [g]Concolor Research, Boulder, Colorado, USA; [h]College of Education, University of Texas, Austin, Texas, USA; [i]University of Massachusetts, Amherst, Massachusetts, USA

ABSTRACT
OpenSciEd is an ambitious effort to implement the vision of the *Framework for K-12 Science Education* and the *Next Generation Science Standards* broadly across the United States. The premise of OpenSciEd is that high quality instructional materials can play a critical role in transforming science teaching and learning at a broad scale. To achieve its goal, this collaborative project is developing instructional materials for middle school science that support the shifts in practice required to achieve the outcomes called for by the *Framework for K-12 Science Education* and the *Next Generation Science Standards* at a large scale. The OpenSciEd Middle School Program development project is addressing the challenge of making large changes in practice at a large scale through attention to (1) who participates in design and development, and how; (2) providing explicit guidance for developers in a comprehensive design framework; and (3) a design and development process that ensures participation from the desired participants and adherence to the guidelines of the design framework. The resulting instructional materials have shown promise in external reviews and field tests, but their success in achieving the project's goals for transforming science will depend on the circumstances in which the program is implemented.

KEYWORDS
Instructional materials; Next Generation Science Standards; middle school; design framework

Introduction

The OpenSciEd Middle School Program development project is an instructional materials development effort whose goal is to support a transformation of science teaching and learning across the United States. Launched in 2017, the project is a collaboration of materials developers, educational researchers, classroom educators, and educational leaders that has been funded by a consortium of foundations to create a comprehensive science program for grades 6–8 that will be distributed for free under an open content license.

CONTACT Daniel C. Edelson dedelson@bscs.org BSCS Science Learning, 5415 Mark Dabling Blvd, Colorado Springs, CO 80918.

The transformation we seek in this project is ambitious in its nature and its scale. We seek a shift in the practices of teachers and students that will enable them to achieve the outcomes called for by the National Resource Council's *Framework for K-12 Science Education* (NRC Framework) (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). The scale of the transformation that we seek is a significant fraction of the thousands of schools and districts across the twenty-four states that have adopted the NGSS and the additional twenty that have developed their own standards based on recommendations in the NRC framework (NSTA, n.d.).

In our effort to achieve this transformation, we have approached the challenges of design and development with careful attention to three sets of design decisions:

who participates in the design (the participants);

- what guidelines are provided to developers (the design framework); and
- how the design and development proceeds (the development process).
- These three sets of decisions and how they have been influenced by the nature and scale of the transformation we seek are the focus of this article.

The central premise of this work is that instructional materials can play an important role in changing classroom practices and the outcomes that result. Curriculum-focused efforts to improve science and math education since the Sputnik era in the United States bear that premise out (DeBoer, 1991; Rudolph, 2002). However, we do not believe that instructional materials are sufficient on their own to bring about the type and scale of transformation that we seek. We believe that they must be part of a concerted effort to address systemic factors that can impede or enhance change (National Academies of Sciences, Engineering and Medicine, 2018).

The specific shifts in teaching and learning we seek to support with this program have shaped its development and given it distinctive characteristics. So, we begin this article with a description of the shifts we seek to bring about. We follow that with a description of the approach to design and development that we have taken in this project, with sections devoted to each of the three key sets of decisions we have made, who participates, what guidelines we provide to developers, and how we conduct design and development. We conclude with a discussion of trade-offs made in the development of the instructional materials and their vulnerability to the circumstances of their use.

Transforming teaching and learning to achieve the outcomes called for by the NRC Framework and the NGSS

We call the changes in teaching and learning practices that we seek a *transformation* because they are dramatically different from what is taking place in most American science classrooms today. To effect a true transformation, we seek lasting change, not the kind of short-term change followed by a reversion to prior practice that is all too common in educational reform once the initial attention and investment are exhausted. The key components of this transformation reflect the outcomes called for by the NRC Framework and the NGSS. They include:

- Students learn through an iterative process in which they build new understanding and competence with practices through investigations of complex phenomena. These investigations enable them to build new understanding and abilities through the processes of explaining phenomena and designing solutions to problems.
- The student is an active investigator who constructs understanding in collaboration with peers under the guidance of the teacher, in contrast to the role of passive absorber of information that is common in schools today.
- The teacher's role is to create a context for learning, choreograph learning experiences, and facilitate productive social interactions. In the latter role, the teacher is responsible for initiating and facilitating discussions in which students pose questions, plan investigations, share predictions and observations, collect evidence, build models, and propose, debate, and seek consensus on causal relations. This role is a shift from the role of conveyer of information, which is common in schools today.
- The teacher takes responsibility for creating an equitable learning environment that supports learning for all students by taking advantage of funds of knowledge (Moll et al., 1992) that students from different backgrounds bring to the classroom and removing inequitable obstacles to learning for students across the wide range of abilities, prior experiences, and identities that are found in American classrooms.

While the effectiveness of this approach is supported by research (National Research Council, 2012), the challenge of making these shifts is substantial for teachers and students. The scale at which we seek to bring about this transformation adds an additional challenge, not just because of the large numbers, but because of the diversity in student populations, teaching contexts, and teacher backgrounds across American schools today.

The role instructional materials can play in supporting changes in teaching and learning

The OpenSciEd Middle School Program development project is focusing on instructional materials because well-designed instructional materials can support shifts in teacher and student practices. From the teacher's perspective, instructional materials serve as a tool that teachers use to design instruction (Brown, 2009; Davis et al., 2016; Remillard, 2005). From the developer's perspective, they offer the opportunity to provide a teacher with a representation of an approach to teaching and learning. Instructional materials can present a vision of what an approach looks like in practice. They can also support teachers and students in bringing that vision to life in the classroom.

The need for additional supports

Supporting a significant shift in practice is a lot to ask of instructional materials, however. Conditions must favor it. First, the teacher must be open to the shift and have a motivation to make the shift that is matched to the amount of effort that shift will require. Second, because the shift between current teaching practices and those required to achieve the outcomes called for by the NRC Framework and the NGSS is large, most teachers will require more support for understanding the shifts and how to implement them than a static set of instructional materials can provide. In most cases, teachers will require a program of facilitated professional learning (National Academies of Sciences, Engineering and Medicine, 2015). More often than not, teachers making such a large shift in practice will also require professional and emotional support from colleagues and supervisors. Finally, the outcome measures for teachers and students should encourage and reinforce the shift. Teacher performance evaluation and student assessment systems should be aligned with the desired changes in practices and outcomes, but they should also reflect the fact that change in professional teaching practice takes time and proceeds through stages (Loucks-Horsley et al., 2009).

Design and development to foster transformation in teaching and learning

A major focus of research-based design and development for science education reform since the late 1950s has been the design of instructional materials. This work has focused heavily on design frameworks, often referred to as *instructional models* (e.g., Abraham, 1998; Bybee, 2015; Eisenkraft, 2003). Throughout this period, science education reformers have drawn on theory and research findings to develop design frameworks that provide guidelines for the creation of instructional materials for use in classrooms. In addition to the work on instructional materials, there has been a parallel strand focusing on design frameworks for teacher professional learning. However, teacher professional learning has too often been treated as a separate path to improvement, independent of the use of high-quality instructional materials. In contrast, the work on the OpenSciEd Middle School program has focused on design frameworks for both classroom instruction for students and professional learning for teachers. This attention to how instructional materials and professional learning can work together to support shifts in teacher practice is an important characteristic of the OpenSciEd approach to design and development.

A second important characteristic of our approach to design and development is that we have broadened our focus beyond design frameworks. We believe that the outcome of design and development is influenced as much by who uses the design frameworks and how they are using them as it is by the frameworks themselves. Therefore, the developers of the OpenSciEd Middle School Program have been just as attentive to decisions about (1) the participants in design and development and (2) the design and development process as they have been to decisions about the design framework. To reflect that, we describe the decisions we made regarding the framework, the participants, and the processes for design and development in the sections that follow.

The participants in design and development

Decisions about who participates in the design and development of instructional materials and how they participate can have as big an impact on the product as any other design or development decisions. Decisions about who participates determine the expertise, the lived experience, and the perspectives that are brought to all subsequent decisions. Recognizing this, the OpenSciEd project has intentionally sought representation of specific constituencies in design and development and then established development processes to make sure that all of their perspectives are weighed. The decisions about who should participate were made over time, in a bootstrapping process. This process began with four individuals who made initial decisions about the types of participants that should be involved in the process and recruited a larger group of individuals in those categories. This larger group then made a second set of decisions about participants.

The OpenSciEd development process was conceived of from the beginning as needing to be a collaboration among diverse partners bringing different expertises and sensitivities. The process began with a 4-person "interim design team" consisting of one representative each from a philanthropic foundation, a national nonprofit focused on development and implementation of standards, a state education agency, and a nonprofit organization dedicated to science education research and development.[1] Their vision was influenced by lessons from efforts to implement the Common Core State Standards for Math and English Language Arts and recommendations gathered through commissioned reports (Bybee & Chopyak, 2017; National Academies of Sciences, Engineering and Medicine, 2018). The deliberations of this initial design team led to the following decisions about who should participate in the project and how:

- *State-level education leaders*. To ensure that the OpenSciEd program would meet the actual needs of educators in NGSS states, the interim design team decided to establish a *state steering committee* with leaders from state education agencies or state-wide technical assistance providers as members. To join the state steering committee, the agency had to commit to supporting a field test involving a minimum of 12 teachers at each middle school grade in their state. The interim design team decided that all major decisions about the form or content of the program would require approval by the state steering committee.
- *Educational researchers*. To ensure that the research base behind the NRC Framework and the NGSS would properly inform the OpenSciEd materials, the interim design team decided that science education researchers should be integrally involved in the design and development of the program.
- *Instructional materials developers*. To ensure that the materials could be completed in accordance with the goals established by the state-level leaders and the educational researchers, the interim design team established a set of criteria and a process for the selection of expert instructional materials developers to conduct the design and development for the program.

The interim design team then recruited the state steering committee and worked with the state steering committee to select a multi-institutional team of developers and researchers to conduct the actual program design and development. The developers consortium added four more categories to the list of essential participants in the process:

- *Teachers*. To ensure that OpenSciEd instructional materials reflect a sound understanding of (1) students, their motivations, capabilities, dispositions; (2) classroom dynamics; (3) school and community contexts; and (4) practical constraints, the Consortium called for the participation of teachers as advisors, developers, reviewers, and testers of the program.
- *Students*. To ensure that OpenSciEd instructional materials take into account the commonalities and differences across the diversity of students in public middle schools

[1]The four organizations that initiated the OpenSciEd Middle School Program development project were the Carnegie Corporation of New York, the Louisiana Department of Education, Achieve, Inc., and BSCS Science Learning.

in the United States today, the Consortium called for the participation of students as informants and testers of the program.

- *Science experts*. To ensure that OpenSciEd instructional materials present current scientific understanding and unresolved questions accurately and capture the excitement of both historically resolved and currently unfolding science, the Consortium called for the participation of experts in science as advisors and contributors.[2]
- *Educational specialists*. To ensure that OpenSciEd instructional materials reflect experience and expertise of practitioners in important areas for the success of the program (e.g., literacy, universal design for learning, emerging multilingual learners), the Consortium called for the participation of educational specialists as advisors, reviewers, and developers.

In the ensuing design and development process, the representatives of the seven constituencies described above, with the expertise and experience that they have brought to their roles, have determined both the key characteristics of the program and the particular ways those characteristics have been implemented in specific units, lessons, and activities. In the Design and Development Process section below, we describe the processes that were put in place to engage each of these constituencies.

The design framework

The design framework for this project provides guidelines to developers grounded in research and practical experience. However, the framework is significantly broader in its scope and more fine-grained in its guidelines than is typically found in instructional models. In addition, because it was recognized from the beginning of the design process that it was going to be necessary to provide resources to support professional learning to accompany the program, the design framework covers two categories of materials: instructional materials to support student science learning and professional learning resources to support teacher professional learning.

The design framework for instructional materials

The instructional model is the heart of any design framework for instructional materials. The developers consortium selected Next Generation Science Storylines (NextGen Storylines) (Reiser et al., this issue) as the instructional model for two reasons. Not only does this instructional model place phenomenon-driven, three-dimensional learning called for by the NRC Framework and NGSS at the center of teaching and learning, but it had already been used to create instructional units that received the highest possible ratings for quality of "design for NGSS" from Achieve's Peer Review Panel for Science (Achieve, n.d.) prior to its selection for this project.

While the NextGen Storylines instructional model provides the heart of the OpenSciEd design framework, the members of the state steering committee and the developers consortium felt that the nature and scope of the desired transformation require design guidelines that are both broader and more specific than the NextGen

[2]Though not included in the original list of essential expertise, the Consortium has enlisted experts in indigenous understanding and knowledge-building practices as advisors and contributors.

Storylines instructional model provides. They needed to be broader to address the challenges of scale. They needed to be more detailed for two reasons: (1) to ensure that the state steering committee and the developers consortium agreed about the critical attributes of the product that the developers would create and (2) to provide a structure to maintain consistency across materials that would be developed and refined by multiple teams over a four year development process.

The need for broad and detailed guidelines for the developers led to the first major development effort of the project, the creation of the *OpenSciEd Design Specifications* (Edelson & Mohan, 2018). These guidelines were called *specifications* because they were created to serve as requirements for the developers, just as engineering specifications do in construction projects. The *OpenSciEd Design Specifications* contain guidelines about aspects of the materials that the state representatives and developers viewed as critically important. These aspects are captured by the titles of the thirteen chapters in the specifications document (Table 1).

These chapters were developed by writing teams assembled for the purpose of creating the specifications. Every chapter writing team was led by one or more educational researchers with expertise in the chapter's topic. In addition to being authors of scholarly works on their topic, many of these educational researchers had previously served as editors or chapter authors for National Science Teacher Association publications about the NGSS, indicating an existing commitment in the practical applications of their research. With a few exceptions for practical reasons, every writing team included a minimum of two teachers or specialists employed by state or local agencies. These practitioners were nominated by state steering committee members. Chapter writing teams also included individuals with academic or practical expertise relevant to the chapter topic, who were selected by the team leader. All chapter drafts went through two rounds of review by the state steering committee and revision before the committee approved them.

The guidelines in these chapters address two challenges, corresponding roughly to the nature and the scale of the transformation we seek. The chapters focused on the nature of the transformation target the vision of learning described by the NRC Framework. They prescribe how instructional materials should be created to support implementation of the three-dimensional learning of disciplinary core ideas, science and engineering practices,

Table 1. The chapters in the OpenSciEd design specifications (OpenSciEd, 2018a).

Chapter	Title
1	Instructional Model
2	Equitable Science Instruction for All Students
3	Assessment to Inform Teaching and Learning
4	Designing Educative Features
5	Science and Engineering Practice (SEP): Asking Questions and Defining Problems
6	SEP: Planning and Carrying Out Investigations
7	SEPs: Developing and Using Models, Constructing Explanations, and Designing Solutions
8	SEPs: Analyzing and Interpreting Data and Using Mathematical and Computational Thinking
9	SEPs: Arguing from Evidence and Obtaining, Evaluating, and Communicating Information
10	Crosscutting Concepts
11	Classroom Routines
12	Integration of English Language Arts and Mathematics
13	Meeting Practical Needs and Constraints of Public Education
14	Guidance on Modifying Instructional Units.

and cross-cutting concepts described in the Framework. The other guidelines address issues that will arise when trying to implement this transformation at scale across the diversity of student populations, teacher backgrounds, and organizational contexts found in public education in the United States. The guidelines in the chapter on equitable instruction address both. The guidelines in this chapter "are rooted in a commitment to restorative justice through privileging multiple ways of knowing, being, and valuing as a fundamental human condition, and they promote the rightful presence for all students across the multifaceted scales of justice" (Bell et al., 2018, p. 12). Further, they are designed to guide developers to the creation of instructional materials that "support expansive cultural learning pathways for youth working from an asset perspective" (Bell et al., 2018, p. 12).

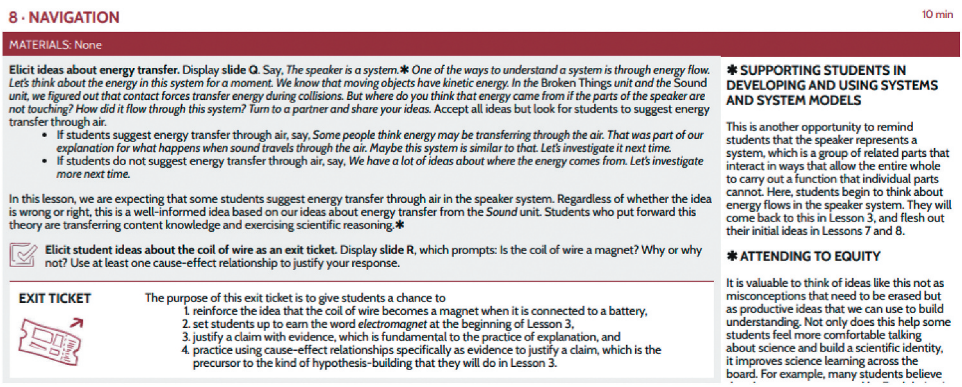
The design framework for professional learning

As we stated above, it was recognized from the inception of this project that the program would need to offer support for teacher professional learning in order to achieve its ambitious goals. This made it important to have a framework for the design of professional learning. The framework we developed is grounded in three key research findings: teachers make sense of new pedagogical ideas through familiar, preexisting lenses (Spillane et al., 2002); without professional learning opportunities teachers' enactment of reform-oriented curriculum materials can significantly vary (McNeill et al., 2017); and grounding professional learning in curriculum materials is more effective way to support teacher learning than providing teachers with teaching methods or curriculum alone (Lynch et al., 2019).

The design framework we developed covers two important contexts for professional learning: learning in the course of planning, enacting, and reflecting on instruction; and learning through participation in facilitated professional learning experiences. The framework is articulated across two documents, one dedicated to each of these contexts. We describe each below.

Guidelines for supporting teacher learning in the course of planning, enacting, and reflecting on instruction are included in Chapter 4 of the design specifications for the instructional materials (Davis & McNeill, 2018). These guidelines call for the inclusion of educative resources (Davis & Krajcik, 2005; Davis et al., 2017) within the instructional materials. Many of these guidelines are implemented through the inclusion of callouts and examples in the teacher guide for each unit. Callouts are notes that appear in the teacher materials for the purpose of providing teachers with guidance or background information beyond the core descriptions of objectives and procedures that are the heart of the teacher materials (e.g., Figure 1). OpenSciEd callouts fall into one of four categories: (1) rationale for why an activity is included or why the developers have written it the way they have; (2) guidance on how to implement an activity for teachers (e.g., facilitating equitable discussions, developing a science and engineering practice, assessing specific outcomes); (3) suggestions for how to support students from specific populations through the activity or how to manage classrooms with different populations of students represented; (4) ideas for how to shorten or extend certain activities.

In addition to callouts, the framework calls for examples of student work in the teacher guides. Their role is to help teachers develop a more concrete vision of how the activities



8 · NAVIGATION

10 min

MATERIALS: None

Elicit ideas about energy transfer. Display **slide Q**. Say, *The speaker is a system.*✱ *One of the ways to understand a system is through energy flow. Let's think about the energy in this system for a moment. We know that moving objects have kinetic energy. In the* Broken Things *unit and the* Sound *unit, we figured out that contact forces transfer energy during collisions. But where do you think that energy came from if the parts of the speaker are not touching? How did it flow through this system? Turn to a partner and share your ideas.* Accept all ideas but look for students to suggest energy transfer through air.

- If students suggest energy transfer through air, say, *Some people think energy may be transferring through the air. That was part of our explanation for what happens when sound travels through the air. Maybe this system is similar to that. Let's investigate it next time.*
- If students do not suggest energy transfer through air, say, *We have a lot of ideas about where the energy comes from. Let's investigate more next time.*

In this lesson, we are expecting that some students suggest energy transfer through air in the speaker system. Regardless of whether the idea is wrong or right, this is a well-informed idea based on our ideas about energy transfer from the *Sound* unit. Students who put forward this theory are transferring content knowledge and exercising scientific reasoning.✱

Elicit student ideas about the coil of wire as an exit ticket. Display **slide R**, which prompts: Is the coil of wire a magnet? Why or why not? Use at least one cause-effect relationship to justify your response.

EXIT TICKET

The purpose of this exit ticket is to give students a chance to

1. reinforce the idea that the coil of wire becomes a magnet when it is connected to a battery,
2. set students up to earn the word *electromagnet* at the beginning of Lesson 3,
3. justify a claim with evidence, which is fundamental to the practice of explanation, and
4. practice using cause-effect relationships specifically as evidence to justify a claim, which is the precursor to the kind of hypothesis-building that they will do in Lesson 3.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

This is another opportunity to remind students that the speaker represents a system, which is a group of related parts that interact in ways that allow the entire whole to carry out a function that individual parts cannot. Here, students begin to think about energy flows in the speaker system. They will come back to this in Lesson 3, and flesh out their initial ideas in Lessons 7 and 8.

✱ ATTENDING TO EQUITY

It is valuable to think of ideas like this not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, many students believe

Figure 1. A page from an OpenSciEd teacher guide, showing callouts on the right.

described in the teacher materials might play out. Specifically, they are designed to enable teachers to anticipate the ideas that their students might express in the course of the activities and how those ideas might be expressed in the work products that students will create in those activities. In addition to actual examples of student work products, the framework calls for the inclusion of transcripts of teacher/student discussions in the teacher materials. These are not actual transcripts, but examples of what teachers might say in the course of facilitating activities and discussions and how students might respond. While these student responses are not word-for-word examples from actual classrooms, they are composites based on observations and reports from pilot and field test classrooms.

Guidelines for creating resources to support facilitated professional learning experiences in workshops or similar settings are contained in the *OpenSciEd Professional Learning Design Principles* (OpenSciEd, 2018). They respond to the request from the state steering committee that the developers consortium create resources that can be used by states, districts, and schools to provide professional learning experiences for teachers prior to and during their initial enactment of the program, as well as on a continuing basis through the early years of using the program. These guidelines implement recommendations in *A Guide to Implementing the Next Generation Science Standards* (National Research Council, 2015, pp. 41–46) that are grounded in research on professional development (Desimone, 2009; Garet et al., 2001; Penuel et al., 2007) suggesting that teachers should have learning opportunities that: focus on specific content, connect to teachers' instructional practice, engage teachers actively, support collaboration, provide sufficient time, and offer a coherent and ongoing system of support. They also implement a theory of action that teacher learning should explicitly be grounded in classroom practice through the use of video cases of teachers' classrooms (Roth et al., 2011) and supports for teacher reflection about genuine problems of practice in their own classrooms (Wilson, 2013).

Based on these recommendations, we developed a framework for the design of facilitated professional learning that weaves together learning to implement the OpenSciEd approach with learning to implement specific units. This framework calls for the creation of resources to support facilitated professional learning for each unit in the program. The framework calls for the facilitated professional learning developed for each unit to both familiarize the teacher with the specifics of that unit and to use that unit as a context for building competence with an important aspect of the OpenSciEd approach. The specific aspects to be targeted by these professional learning experiences were not specified in the framework. In practice, some of the focuses for this professional learning were selected because of their centrality to the OpenSciEd approach and others were selected based on feedback from field test teachers through a process described in the Design and Development Process section below.

The complete design framework

The design framework for the OpenSciEd Middle School Program is large and complex. It is not contained in a single document but is spread across the design specifications for instructional materials and professional learning, as well as other guidelines for writers that have been created to record and share design decisions that have been made over the course of the project. The complete framework is both broad in scope and specific in its details to address two goals and two needs:

- The goal of supporting specific changes in classroom practices,
- The goal of supporting substantial changes in practice across diverse settings,
- The need to have shared expectations among the key stakeholders in the program,
- The need to have consistency across a large project, involving multiple development teams and changing personnel over an extended period.

We represent the complete framework as a set of concentric circles with the instructional model at the center (Figure 2). We envision the design process as proceeding generally from considerations in central rings to considerations in peripheral rings. This implies that decisions in central rings are more fundamental, but decisions in outer rings can modify or add to decisions made in more central rings.

The design and development process

The design and development process employed by the OpenSciEd middle school effort reflects the decisions about who should participate and the design framework described above. Both of these place significant requirements on the process, which we describe in this section. There have been two key stages in the development process. In the first stage, we developed a scope and sequence, and in the main development stage we have developed the eighteen units that comprise the middle school program.

The design and development process for the scope and sequence

Prior to developing the instructional materials themselves, it was necessary to create a scope and sequence document outlining the three year program. However, developing the scope and sequence (Figure 3) revealed significant differences in the way that the standards were written across the 10 states represented in the state steering committee. Five states' policies specified the grade at which each standard is to be taught, and five specified only that all standards had to be met by the end of eighth grade. Further, among the states with grade-

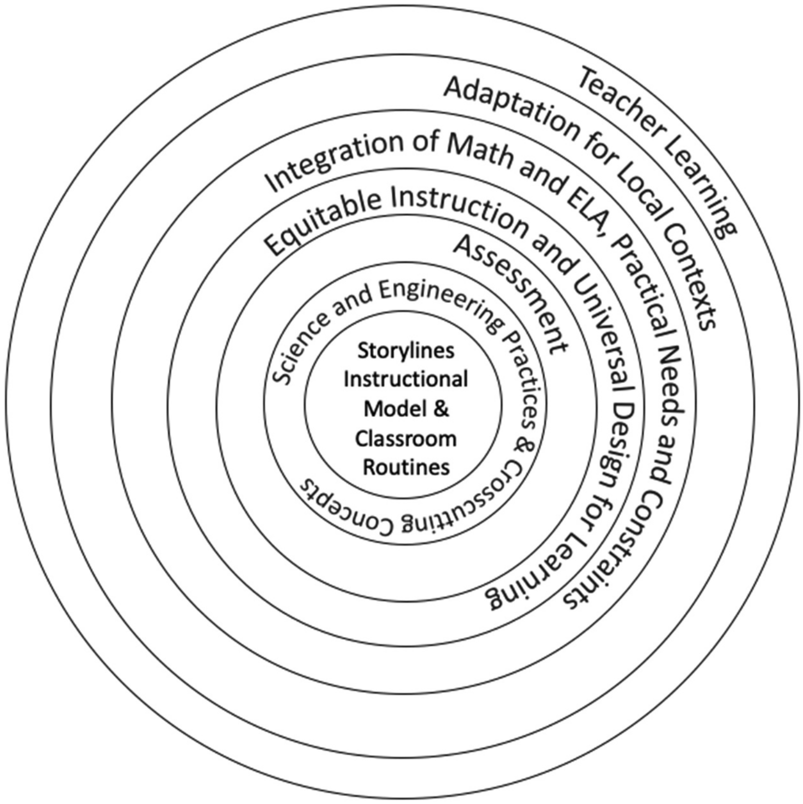


Figure 2. The issues addressed in the OpenSciEd design framework.

specific standards there was very little consistency in the grade at which specific standards were placed. For any particular performance expectation in the NGSS, the probability of any two states placing it at the same grade level was only 35% on average. In response to a report from the developers consortium on the inconsistency of standards across their states, the state steering committee authorized the developers to create a sequence of instruction based entirely on teaching and learning considerations without regard to their state standards documents. At the same time, though, the committee requested that the developers consortium create guidance for districts and schools on how to modify the sequence of units to meet local constraints.

The next step in the development of the scope and sequence was to identify collections of 3–5 disciplinary core ideas from the NGSS that could be taught in the context of a category of phenomenon (e.g., storms, metabolic processes, collisions). The idea was that each bundle of core ideas would provide learning objectives for a 4–6 week instructional unit anchored by a single phenomenon. We then identified possible sequences of these bundles that would allow us to design later units to build on and reinforce ideas from earlier units. Next, we identified science and engineering practices and crosscutting concepts from the NGSS that were likely to be most useful to students in making sense of each bundle of disciplinary core ideas. At this point, we were able to sequence our bundles of disciplinary core ideas, science and engineering practices, and crosscutting concepts into an initial,

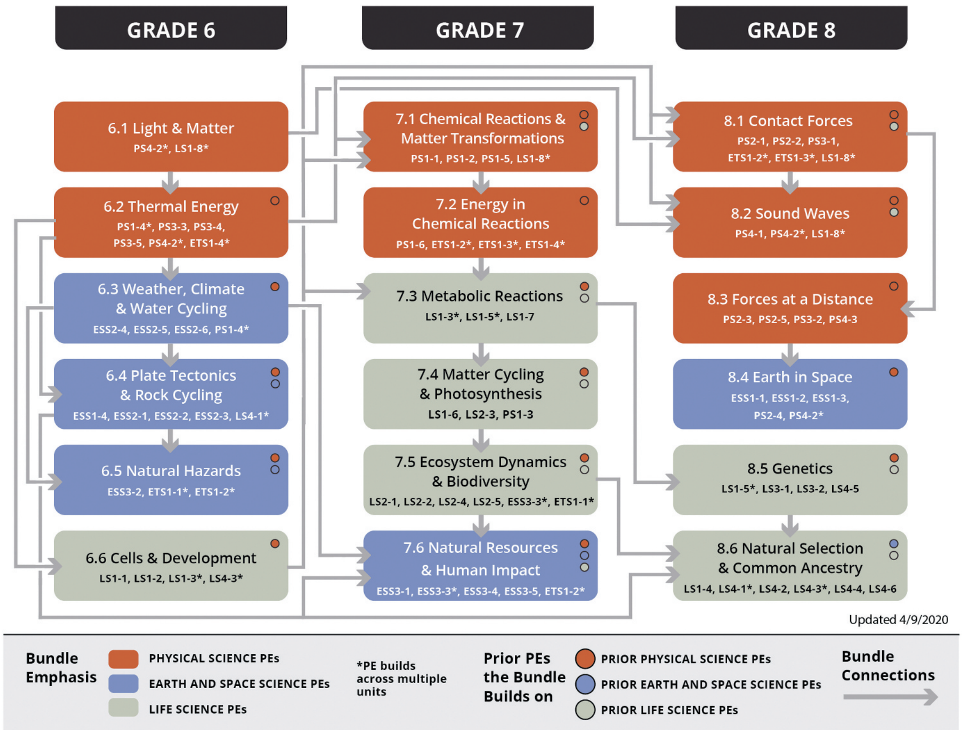


Figure 3. A representation of the OpenSciEd scope and sequence.

tentative scope and sequence. From there, we proceeded through multiple cycles of re-bundling and re-sequencing in an effort to balance considerations such as having a mix of life, physical, and Earth and space science each year, having a focus on each practice and crosscutting concept in at least one unit each year, and maintaining consistency with the sequence of the Common Core Standards for Mathematics (National Governors Association, Center for Best Practices & Council of Chief State School Officers, 2010) over the middle school years.

Because many life science and Earth space science ideas build on physical science ideas, this design process resulted in a sequence with physical science bundles at the beginning of each year and life science and earth space science bundles later in the school year. Because certain disciplinary core ideas depend on mathematical concepts that are placed at the seventh or eighth grade in the *Common Core State Standards for Mathematics* (Common Core State Standards Initiative, 2010), some units were placed later in the sequence than they might have been without considering dependence on math competencies.

The scope and sequence went through several rounds of review and feedback between the state steering committee and the developers consortium before being approved by the committee in March 2018. The scope and sequence has only required minor changes over the course of the development process to address issues raised in the course of writing the materials and field testing them.

The design and development process for units

In the development phase, eighteen individual units of instruction have been written by small teams of professional instructional materials developers working collaboratively with members of the constituencies described in the *Who Participates* section above. The development process intended to enable these teams to create units by applying the design framework in a way that reflects the viewpoints and expertise of the diverse participants in the process. With the experience of 2.5 years of development, this process has been refined and systematized to improve quality, consistency, and efficiency.

At the heart of the OpenSciEd development process is the process developed by the Next Generation Science Storylines Project at Northwestern University to implement the NextGen Storylines approach. This process, in turn, was based on a series of collaborative research and development efforts in instructional materials development, including the Center for Learning Technologies in Urban Schools (D'Amico, 2010), the Center for Curriculum Materials in Science; and the Investigating and Questioning our World through Science and Technology Project (IQWST) (Krajcik et al., 2008).

The OpenSciEd unit development process consists of five phases:

Conceptual design. In the conceptual design phase developers:

(a) analyze learning objectives carefully to articulate how students can demonstrate their achievement of them (Krajcik et al., 2008),
(b) identify candidate phenomena to anchor the unit and select one that will engage students and motivate learning of the complete set of objectives, and
(c) develop an outline—the "storyline"—for the unit that provides a sequence of investigations that are coherent from the students' perspective and enable them to construct an understanding of the targeted concepts (Reiser et al., this issue).

Initial writing. In the initial writing phase, the storyline from the conceptual design process and the specifications are used to guide the writing of individual lessons.

Field test and external review. In the field test and external review phase, the units are taught in their entirety as part of a field trial, and data is gathered from students and teachers participating in the trial. They are also sent to external reviewers for feedback.

Redesign. The redesign phase parallels the conceptual design phase to develop a plan for revising the units to address issues identified during the initial writing phase and exposed through the field test and external review.

Revision. In the revision phase, writers implement revisions suggested by the redesign process and prepare the materials for public distribution.

The OpenSciEd middle school project has implemented this process in a way that brings in all of the required categories of participants and meets the design specifications described in the preceding sections. In the following sections, we describe how we do this.

Processes to ensure participation of all categories of participants

Several specific activities in the development process are designed to bring in important constituencies (Table 2). We describe them below.

Table 2. Teachers' reports of frequency of activities by students across six units. Teachers selected one of the following for each unit: 0 = In no lessons, 1 = In a few lessons, 2 = in half the lessons, 3 = in most lessons, 4 = in nearly every lesson.

Activity	Mean	Standard deviation
Students discussed connections between the focus of the day's lesson and the anchoring phenomenon.	2.279	0.878
Students discussed what we figured out in a previous lesson at the beginning of class.	2.882	0.82
Students updated the Driving Question Board.	1.391	0.861
Students discussed what they figured out at the end of the lessons.	2.797	0.833
Students discussed the knowledge they made that helped them make progress on questions from the Driving Question Board.	1.725	0.938

Advisory committees. The design and development team for each unit is advised by a committee recruited for that unit. Advisory committees typically are chaired by a science education researcher with expertise in the specific disciplinary core ideas of the unit. Every advisory committee includes a minimum of two teachers nominated by members of the state steering committee. Advisory committees may also include science content experts and educational specialists with expertise relevant to the unit and its goals. Advisory committees typically meet face to face with the development team for a design conference early in the unit development process to explore candidate phenomena and storylines. These design conferences frequently include members of the developers consortium—educational researchers and developers—who have relevant expertise. In addition to their role in design conferences, the members of an advisory committee typically consult with the development team regularly through the conceptual design and writing process. At the beginning of the redesign phase, the advisory committee participates in a second design conference to advise on revisions based on field test and external review feedback, and they continue to advise individually throughout the revision process.

Student interest surveys. During the conceptual design phase, developers conduct surveys of students across all ten partner states to gauge their interest in different anchoring phenomena. These surveys are drawn from the work of Penuel et al. (2018) On the surveys, which are distributed to classes participating in the field test described below, students are given a brief description of several candidate phenomena or, in some cases, examples of driving questions about candidate phenomena. The students are asked to rate their interest in studying these phenomena or questions in a future OpenSciEd unit on a numerical scale. We typically receive responses from more than 400 students, and we disaggregate data across populations that have been historically underserved by science education (e.g., Figure 4).

Classroom pilot testing of key activities. Most unit development teams recruit one or two teachers to pilot test key activities in their classrooms. For example, activities in the anchoring phenomenon routine are typically pilot tested during the conceptual design phase to see how well they engage students and to collect information about the ideas and questions that students have about candidate anchoring phenomena. This information is then used to select the anchoring phenomenon for a unit and to design the storyline sequence to be coherent from the students' perspective. Other pivotal activities for the

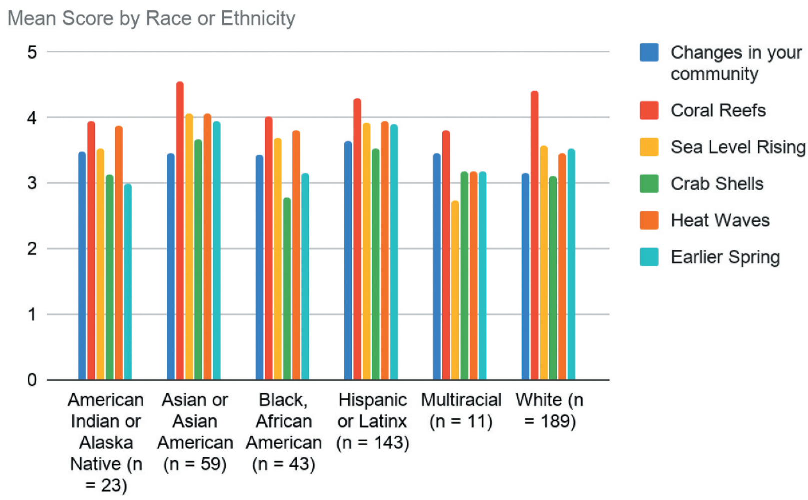


Figure 4. Results from a student interest survey for a unit on natural resources, showing results disaggregated by race and ethnicity.

storyline and activities that developers have questions about may also be pilot tested during the conceptual design and initial writing phases to identify weaknesses and collect information about students' ideas and examples of student work for use in teacher materials.

State steering committee design reviews. At regular intervals throughout the conceptual design, initial writing, redesign, and revision phases, the development team conducts design reviews with members of the state steering committee or their designees. These review sessions, typically attended by 4–8 state representatives, provide an opportunity for unit development teams to obtain feedback on their current designs and get input on pending design questions. It provides an opportunity for state representatives to provide input from their positions as state-wide leaders.

Consultation by experts. To supplement the expertise and experiences of the members of the developers consortium, the consortium has engaged outside experts to serve as consultants. One set of experts has served as consultants across the entire program in three areas: assessment, design for emerging multilingual learners, and design for equitable instruction. These consultants perform three tasks. They create practical guidelines for use by all development teams on ways to implement the requirements of the specifications in their area of expertise. These guidelines have been provided to all unit leads and writers. They provide advice to unit development teams on how to address issues that arise in the course of developing their unit. Finally, they conduct reviews of units and provide feedback. A second set of experts have been engaged as consultants on specific units. These experts have participated in a range of activities including participation in design conferences and other unit advisory committee activities, advising on phenomenon-specific issues, and sharing or creating resources to be included in the instructional materials. For example, members of indigenous communities from different parts of the world contributed interviews about understandings of astronomy developed by their communities to a unit on space science.

Field testing. At the completion of the initial writing process, every unit is field tested. The field test for the OpenSciEd middle school units is unusually large, with teachers from all 10 partner states. Field test teachers were selected by the representatives on the state steering committee through a process that varied from state to state. All states sought to have underserved student populations represented in their sample and to have teachers who would be successful at implementing the shifts. Some states advertised for volunteers; some recruited specific teachers; Some prioritized specific geographic regions, and some prioritized teachers who could be leaders in implementation efforts once the program is completed. In sum, teachers were selected to serve program-wide and state-specific goals; they were not selected at random or to be representative of teachers in their state overall.

Until the disruption of public education caused by the Covid-19 pandemic, each unit was field tested in at least 45 classrooms. (In the field test of 6 units taking place in the fall of 2020, approximately half as many teachers are participating in the field test of each unit, and most of them are teaching online or through a mix of online and in-person.) In the field test, data to inform the revision of the units is collected from both teachers and students. Teachers provide feedback about units and lessons, including their impressions of student engagement, their pace of instruction, and strengths or weaknesses of the materials. They also provide copies of some student work, and they are invited to provide open-ended feedback on any lessons. Students return surveys about select lessons that include questions about their level of engagement and nature of participation. Field test data are collected and analyzed by a data collection and analysis team associated with the developers consortium, with their findings reported to unit development teams during the redesign phase. Field test findings for their state are also provided to each state steering committee member.

External review. At the same time that units are being field tested, they are submitted to Science Peer Review Panels established by Achieve[3] that use the EQuIP Rubric for Science (Achieve, 2016) "to determine the extent to which they are designed for the NGSS" (Achieve, n.d.). Results of EQuIP reviews are combined with field test findings to inform redesign and revision activities by unit development teams. Revised units are reviewed by Science Peer Review Panels again prior to release and must receive a score of 6 or above on the EQuIP Rubric 9-point scale before they are released. Of the 9 units released prior to November 2020, 7 have received the highest rating (8 of 9), which signifies "Example of High Quality NGSS Design".

Processes to meet the design specifications for instructional materials

The nature and scale of the desired transformation and resulted in a demanding set of design specifications. In response, the developers consortium has developed a careful development process. We described many of the elements of this development process in the previous section to show how we engage specific participants. In this section we focus on an element of the process that is essential to meeting requirements of the design

[3]In 2019, responsibility for curriculum reviews using the EQuIP Rubric for Science was transferred from Achieve to WestEd's NextGenScience Project.

specifications for instructional materials: multiple writing passes in a deliberate order. Because the specifications include so many considerations, the writing is conducted in multiple passes during both the initial writing and the revision phases of development. The focus of the passes tends to shift from the center of the diagram in Figure 2 to the edge.

While it differs from team to team, the first pass typically focuses on the activities of teachers and students and the instructions they each require. If not included in the first pass, the second pass typically focuses on support for the use of science and engineering practices and crosscutting concepts by students in their efforts to make sense of disciplinary core ideas. Considerations of equity and inclusiveness, emerging multilingual learners, Universal Design for Learning are also typically part of the first pass or two, as well.

Later passes tend to focus on details, such as noting connections to math and English Language Arts standards, or tasks that depend on having the current unit draft largely complete. These latter include highlighting assessment opportunities, developing “transfer task” assessments—performance assessments that ask students to apply their understanding in different contexts—and revising for coherence. Revision for coherence entails two reviews, one review of all lessons to ensure that the progression of activities will make sense for students as a series of steps to resolve the questions raised by the anchoring phenomenon, and a second to make sure that all the activities are in place to enable students to understand how each activity they conduct builds on its predecessor(s) and builds toward the goal of the unit.

Processes to meet the design specifications for facilitated professional learning experiences

The resources to support facilitated learning experiences for teachers are developed alongside the units by specialists in the design of professional learning experiences. They are developed during the initial writing phase, used to prepare field test teachers to teach the units in their classrooms, and then revised during the revision phase of the development process.

As described in the overview of the design framework for professional learning, the professional learning resources for each unit are designed to both familiarize teachers with the details of the specific unit and support their learning about a key aspect of the OpenSciEd instructional approach. The developers have selected the aspects of the approach to focus on in these resources based on surveys of field test teachers that ask them, after each unit that they teach, to identify the aspects of the OpenSciEd that they feel least confident about or would like to learn about in future professional learning experiences. Teachers have identified a wide range of issues that have been incorporated into professional learning experiences. These include how to assess students, how to facilitate equitable discussions, and how to support emerging multilingual students and students across a diverse range of abilities.

During conceptual design and the first portion of the initial writing, professional learning developers create the resources for the key aspect of the OpenSciEd approach that has been selected for that unit. Once the conceptual design is complete and the lesson writing for the unit is well underway, the professional learning developers move on to creating the unit-specific resources. In preparation for the field test for each unit, OpenSciEd developers use these resources to prepare facilitators from each partner state, who, in turn use the resources to lead professional learning for field test teachers. The revision of the professional learning resources is informed by information gathered from these facilitators and the field test teachers. Revisions of the professional learning materials take place during the revision of each unit, so that the professional learning resources for each unit are ready for public release at the same time as the unit.

Discussion

At the time of writing, the OpenSciEd middle school program is a work in progress. It represents a set of conjectures (Edelson, 2002; Sandoval, 2004) grounded in research and prior experience that have been shown to have some promise through field testing and external review. In the future, we will be able to evaluate the extent to which it achieves the transformation we seek. In the meantime, there are reasons for both optimism and concern that merit consideration.

Two reasons for optimism can be found in the findings of the external EQuIP review and the field test. The EQuIP review is designed to determine how well a program implements the features that Achieve describes as "designed for NGSS" (Achieve, n.d.). To date, four of six publicly released units have received Achieve's highest rating indicating that it is a high-quality design for the NGSS across all three categories of the EQuIP Rubric: I) NGSS 3D Design, II) NGSS Instructional Supports, and III) Monitoring NGSS Student Progress. The remaining two received the next highest rating indicating that they are high quality designs for the NGSS with room for improvement.

Findings from the field test are encouraging as well. From the students' perspective, more than 90% of students report instruction to be relevant to them. This was true for students from all racial backgrounds (Figure 5). Based on student surveys, we have strong evidence that materials support equitable participation in science. Students from different racial backgrounds, genders, and linguistic backgrounds report they contribute at high levels to class discussion and say their ideas are taken seriously by others (Figure 6).

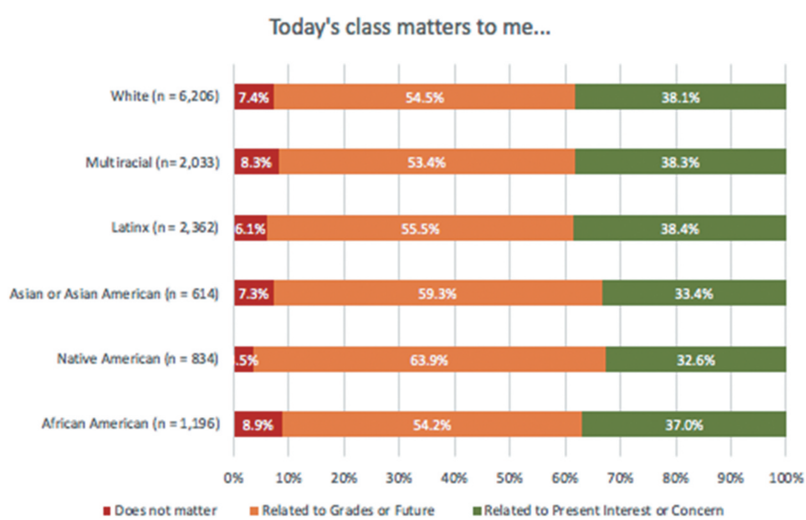


Figure 5. Students' ratings of relevance aggregated across all units and all lessons from the field tests of the first six units developed.

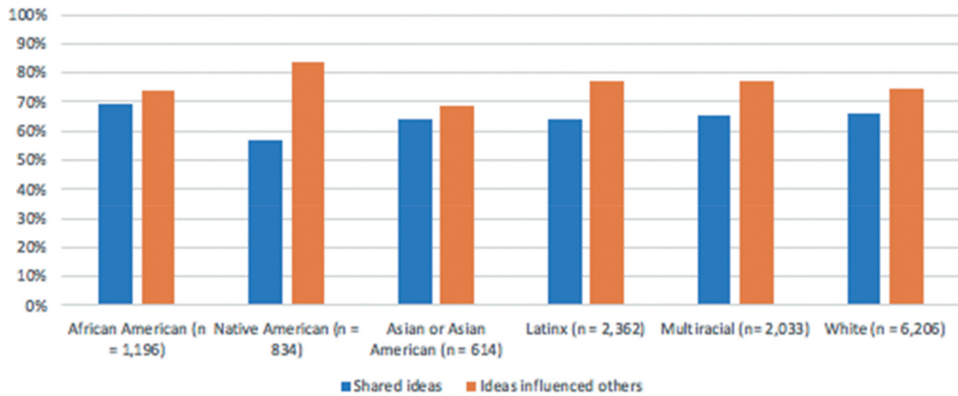


Figure 6. Students' reports of whether they contributed an idea to a discussion and if they thought their contribution(s) influenced others on the day they were surveyed. This chart shows all responses from all students across all surveys from the six units that have been field tested at the time of writing.

From the teachers' perspective, teachers say OpenSciEd units support addressing standards better than past materials. Approximately 93% of teachers report that OpenSciEd materials are "some" or "far" more likely to help students meet state science standards. Over 55% of teachers report that the materials are "far more" likely to help students. There is little variation between states in terms of teachers' perceptions. Teacher feedback is encouraging as well. Teachers say materials meet the needs of a wide variety of students, including special education and gifted students, and both high- and low-achieving students. Teachers report that materials are accessible for struggling readers and there are opportunities to better support students with Individualized Education Programs (IEPs) and students who are learning English. for teachers who serve these groups of students:

- 84% said materials were accessible to struggling readers
- 76% said materials were accessible to students with IEPs
- 68% said materials were accessible to emerging multilingual learners.

In addition, field test teacher reports provide evidence that the desired shifts in practices are occurring (Table 3).

Table 3. The category of participants engaged in each of the design and development activities.

	Design Specifications	Scope & Sequence	Advisory Committees	Student Interest Surveys	Piloting of Key Activities	State Steering Committee Reviews	Consultation by Experts	Field Testing	External Review
State-level science education leaders	X	X				X			
Educational researchers	X	X	X						
Instructional materials developers		X	X						
Teachers	X		X		X			X	X
Students				X	X			X	
Science experts			X						
Educational specialists	X						X		

Despite these positive indicators, we cannot rule out the possibility that the success that we are seeing in the field test doesn't reflect what will happen once the program enters open distribution. There are a number of reasons for concern that we may not achieve the transformation that we seek at the scale we seek. One set of reasons stem from design trade-offs. Another set stems from the risk that the program will not be implemented in conditions that are conducive to its success.

Design trade-offs in the program

As developers, we are keenly aware of the weaknesses of the program. For every activity, lesson, or unit, there are members of the development team who can list things that could be improved and would have been if they had more time. However, when we consider major issues that could have a substantial impact on the success of the program in practice, they are not individual weaknesses scattered across the program. They are the result of two trade-offs made in the design and development process.

The first significant trade-off in our design and development process resulted from the tension between the vision of learning in the NRC Framework and NGSS and the number of performance expectations in the NGSS. We experienced this as a tension because the approach to teaching and learning requires substantial amounts of time to develop understanding of concepts and become proficient at practices, while the amount of time available for science instruction is limited. The developers' perspective on this tension is that meeting the constraint on instructional time of fitting within 180 45-minute class periods per grade level resulted in compromises in the implementation of the NextGen Storylines instructional model. In addition, data collected from teachers in the field test revealed that most teachers were unable to complete units within the number of class periods allocated in the pacing guide for those units during, even though the difference between the pacing guide and teachers' implementation time narrowed as teachers grew more familiar with the instructional approach.

The second important design trade-off is between supporting teacher learning and usability of the instructional materials. To support teachers through the significant shift in practices that the program is designed to support, the design specifications and the EQuIP rubric call for providing teachers with a great deal of guidance and information. Implementing the myriad requirements of the specifications and meeting the demands of the EQuIP rubric has resulted in voluminous teacher guides. The teacher guides for 6-week units range between 250 and 350 pages. While there is a strong rationale for each individual piece of information we provide, the aggregate of all of these individual pieces of information can be overwhelming and may prove to be counterproductive. The desire to support every teacher means that there is a great deal more information than any particular teacher needs or can use. Since all of the information is useful to some teachers and all teachers' needs change over time, we believe that the eventual solution to this challenge will be a digital planning tool that enables teachers to filter out information that does not apply to them at the current time. In the meantime, however, the sheer volume of material for teachers in the linear print and digital materials is likely to be a challenge to usability in many cases.

Circumstances of implementation

In addition to the trade-offs in program design described above, there are reasons for concern that the success of the program will be limited by the circumstances under which schools and districts implement it. In this discussion, we consider four factors, professional learning for teachers, pace of initial rollout, provision of equipment and supplies, and administrative and policy support.

The amount of formal professional learning that is reasonable to expect that districts will provide to teachers when they adopt OpenSciEd has been a topic of discussion from the inception of the project. During the establishment of the state steering committee, all the partner state representatives agreed that the transformation that they seek to implement requires that teachers be provided with dedicated professional learning. Therefore, they instructed the developers to design the OpenSciEd middle school program with the presumption that districts who adopt it will provide formal professional learning to teachers who have never implemented the NextGen Storylines pedagogical approach. In the field test, teachers received a minimum of 6 full days of facilitated, face-to-face professional learning in their first year—4 days in the summer prior to teaching their first unit and 2 in the winter prior to teaching their second unit. In the second and third years, they have received a minimum of 4 days per year. The field test data indicates that this quantity of professional learning was sufficient to develop the understanding, skills, and confidence for a diverse group of teachers working across a wide range of settings to implement the program. The questions that concern us at this time, however, are what percentage of adopting schools and districts will facilitated professional learning to teachers, and what quantity and quality of professional learning will they provide?

While perennially tight budgets in education justify concern, two aspects of the program provide reason for optimism that teachers will be provided with some level of facilitated professional learning. The first is that the program is being distributed as open content, meaning that schools and districts will be able to obtain and use the program at no charge. This distribution model creates the possibility that the money that would otherwise be spent on instructional materials could be used to provide professional learning experiences to teachers. The second is that the resources for professional learning that are being created for the program will also be available at no charge. The availability of these high-quality, curriculum-based professional learning resources could increase the likelihood that districts will provide their teachers with facilitated professional learning experiences.

While the quality and quantity of professional learning that teachers will receive is likely to be the largest factor determining the success of the program, three other factors are likely to be influential as well. The first is the dependence of the program on equipment and supplies to support the investigations that students conduct. At the request of the state steering committee, the developers have kept the cost of these materials as low as possible. However, school district budgets are tight, and there is the possibility that the implementation of the program will be undermined in districts that are unable to bear the complete costs of the equipment and materials. The second is the pace at which districts will choose to roll out the program. In the field test, the program has been rolled out in phases, with each teacher implementing two new units per year over three years. As a result, teachers have had only one new unit to teach each semester and have been able to apply lessons learned from teaching other units repeatedly to each new unit they teach. The field test data indicate that this provided teachers and students with a challenging but manageable pace of change. While we do not have data to support an argument for any specific rollout plan, we are concerned that implementing the complete program for the first time in one year could be overwhelming, leading to poor outcomes that year, and fostering doubts about the program's ability to support positive outcomes. Third, the implementation of this program can be undermined by official policies or messages from leaders that are inconsistent with the program's approach. Of particular concern are the messages sent by the ways that students are assessed and teachers' performances are evaluated.

With a new program, the effect of any of these circumstances will be magnified in the first few years of broad distribution. The experiences of early adopters will have a disproportionate influence on later adoption decisions. If early adopters do not implement the program under supportive conditions and are unsuccessful as a result, that could discourage other districts that might have implemented under supportive conditions from even adopting. As a result, the potential for the program to support transformation at a large scale could hinge on the circumstances under which early adopters implement it.

Conclusion

The project to develop OpenSciEd Middle School Program has demonstrated how the goal of achieving a specific transformation in teaching and learning can be used to develop an approach to design and development that is tailored to the nature and scale of the desired transformation. The OpenSciEd Middle School Project's approach can be characterized in terms of (1) who participates in the process, (2) the design framework that is used to shape the product, and (3) the development process for creating the product. In the OpenSciEd development effort described here, decisions about these three characteristics have been guided by the vision of the NRC Framework and the Next Generation Science Standards, and by the goal of bringing this vision to life in thousands of schools across more than 20 states. While external reviews and field tests have shown signs of promise, the ultimate success of the OpenSciEd program at achieving the transformation the project seeks will depend on decisions about trade-offs made in the development process and the circumstances under which it is implemented once it is adopted.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Bill and Melinda Gates Foundation; Carnegie Corporation of New York; Charles and Lynn Schusterman Family Foundation; William and Flora Hewlett Foundation; Willard Brown.

ORCID

Daniel C. Edelson http://orcid.org/0000-0003-2261-4065
Brian J. Reiser http://orcid.org/0000-0002-2961-0385

Katherine L. McNeill http://orcid.org/0000-0003-3673-6637
Michael Novak http://orcid.org/0000-0002-5784-2554
Zoë E. Buck Bracey http://orcid.org/0000-0003-4826-3582
Jamie Deutch Noll http://orcid.org/0000-0002-3628-2711
Susan M. Kowalski http://orcid.org/0000-0002-2012-6378
Abraham S. Lo http://orcid.org/0000-0003-1365-0101
William R. Penuel http://orcid.org/0000-0001-7096-6669
Katie Van Horne http://orcid.org/0000-0002-6276-5805
María González-Howard http://orcid.org/0000-0003-3575-3937
Enrique Suárez http://orcid.org/0000-0002-6550-8580

References

Abraham, M. R. (1998). The learning cycle approach as a strategy for instruction in science. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 513–524). Kluwer.

Achieve. (2016). *EQuIP rubric for lessons & units: Science (Version 3.0)*. Achieve. https://www.nextgenscience.org/sites/default/files/EQuIPRubricforSciencev3.pdf

Achieve. (n.d.). *Science peer review panel*. Retrieved July 14, 2020, from https://www.nextgenscience.org/peer-review-panel/science-peer-review-panel

Bell, P., Bang, M. E., Buxton, C., Heinz, M., Lee, O., Morrison, D., Rodriguez, A., Tesoriero, G., & Tzou, C. T. (2018). Equitable science instruction for all students. In D. C. Edelson & A. M. Mohan (Eds.), *OpenSciEd design specifications* (pp. 12–24). OpenSciEd. https://www.openscied.org/design-specifications/

Brown, M. W. (2009). The teacher-tool relationship. In J. T. Remillard, G. Lloyd, & B. A. Herbel-Eisenmann (Eds.), *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17–36). Routledge.

Bybee, R. (2015). *The BSCS 5E instructional model: Creating teachable moments*. NSTA Press, National Science Teachers Association.

Bybee, R., & Chopyak, C. (2017). *Instructional materials and implementation of NGSS: Demand, supply, and strategic opportunities* (Report). Carnegie Corporation of New York.

Common Core State Standards Initiative. (2010). *Common Core State Standards for mathematics*. National Governors Association Center for Best Practices and Council of Chief State School Officers. http://www.corestandards.org/assets/CCSSI_Math%20Standards.pdf

D'Amico, L. (2010). The center for learning technologies in urban schools: Evolving relationships in design-based research. In C. E. Coburn & M. K. Stein (Eds.), *Research and practice in education: Building alliances, bridging the divide* (pp. 37–53). Rowman & Littlefield.

Davis, E. A., Janssen, F. J. J. M., & Van Driel, J. H. (2016). Teachers and science curriculum materials: Where we are and where we need to go. *Studies in Science Education*, *52*(2), 127–160. https://doi.org/10.1080/03057267.2016.1161701

Davis, E. A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14. https://doi.org/10.3102/0013189X034003003

Davis, E. A., & McNeill, K. L. (2018). Designing educative features. In D. C. Edelson & A. M. Mohan (Eds.), *OpenSciEd design specifications* (pp. 31–37). OpenSciEd. https://www.openscied.org/design-specifications/

Davis, E. A., Palincsar, A. S., Smith, P. S., Arias, A. M., & Kademian, S. M. (2017). Educative curriculum materials: Uptake, impact, and implications for research and design. *Educational Researcher*, *46*(6), 293–304. https://doi.org/10.3102/0013189X17727502

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. Teachers College Press.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *Journal of the Learning Sciences*, *11*(1), 105–121. https://doi.org/10.1207/S15327809JLS1101_4
Edelson, D. C., & Mohan, A. M. (Eds.). (2018). *OpenSciEd design specifications*. OpenSciEd. https://www.openscied.org/design-specifications/
Eisenkraft, A. (2003). Expanding the 5E model. *Science Teacher*, *70*(6), 56–59. https://my.nsta.org/resource/3471/expanding-the-5e-model-a-proposed-7e-model-emphasizes-transfer-of-learning-and
Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945. https://doi.org/10.3102/00028312038004915
Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, *92*(1), 1–32. https://doi.org/10.1002/sce.20240
Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics*. Corwin Press.
Lynch, K., Hill, H. C., Gonzalez, K. E., & Pollard, C. (2019). Strengthening the research base that informs STEM instructional improvement efforts: A meta-analysis. *Educational Evaluation and Policy Analysis*, *41*(3), 260–293. https://doi.org/10.3102/0162373719849044
McNeill, K. L., González-Howard, M., Katsh-Singer, R., & Loper, S. (2017). Moving beyond pseudoargumentation: Teachers' enactments of an educative science curriculum focused on argumentation. *Science Education*, *101*(3), 426–457. https://doi.org/10.1002/sce.21274
Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice*, *31*(2), 132–141. https://doi.org/10.1080/00405849209543534
National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. The National Academies Press. https://doi.org/10.17226/21836
National Academies of Sciences, Engineering, and Medicine. (2018). *Design, selection, and implementation of instructional materials for the next generation science standards: Proceedings of a workshop*. National Academies Press. https://doi.org/10.17226/25001
National Governors Association, Center for Best Practices, & Council of Chief State School Officers. (2010). *Common core state standards for mathematics*. Authors.
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academy Press.
National Research Council. (2015). *Guide to implementing the next generation science standards*. The National Academies Press.
NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.
NSTA. (n.d.). *About the next generation science standards*. National Science Teachers Association. Retrieved January 3, 2021, from https://ngss.nsta.org/About.aspx
OpenSciEd. (2018). *OpenSciEd professional learning design principles*.
Penuel, W. R., Fishman, B. J., Yamagushi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921–958. https://doi.org/10.3102/0002831207308221
Penuel, W. R., Reiser, B. J., Novak, M., McGill, T., Frumin, K., Van Horne, K., Sumner, T., & Watkins, D. A. (2018, April). *Using co-design to test and refine a model for three-dimensional science curriculum that connects to students' interests and experiences*. Annual Meeting of the American Educational Research Association, New York, NY.
Reiser, B. J., Novak, M., McGill, T. A. W., & Penuel, W. R. (this issue). Storyline units: An instructional model to support coherence from the students' perspective. *Journal of Science Teacher Education*, *32*(7), 805–829. https://doi.org/10.1080/1046560X.2021.1884784
Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211–246. https://doi.org/10.3102/00346543075002211

Roth, K. J., Garnier, H. E., Chen, C., Lemmens, M., Schwille, K., & Wickler, N. I. Z. (2011). Video based lesson analysis: Effective science PD for teacher and student learning. *Journal of Research in Science Teaching*, *48*(2), 117–148. https://doi.org/10.1002/tea.20408

Rudolph, J. (2002). *Scientists in the classroom: The cold war reconstruction of American science education*. Springer.

Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist*, *39*(4), 213–223. https://doi.org/10.1207/s15326985ep3904_3

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research*, *72*(3), 387–431. https://doi.org/10.3102/00346543072003387

Wilson, S. M. (2013). Professional development for science teachers. *Science*, *340*(6130), 310–313. https://doi.org/10.1126/science.1230725