Priority Features of NGSS-Aligned Instructional Materials

Recommendations for Publishers, Reviewers and Educators

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Abstract

The Next Generation Science Standards (NGSS) require classrooms to integrate a three-dimensional approach to teaching and learning such that students routinely use the Science and Engineering Practices and apply the Crosscutting Concepts as primary tools to engage in sense-making to deepen their understanding of the Disciplinary Core Ideas. The Science Teachers Associations of California, Nevada, Oregon, and Washington recognize that teachers have started to make the necessary instructional shifts during this transition period, and they need strong K-12 instructional materials for the vision of the NGSS to become reality. Our review of the current literature on science education suggests that instructional materials need to address two major areas: (1) providing students with relevant learning experiences that cause them to build on or challenge their prior knowledge as they build conceptual understanding to explain phenomenon or design solutions to problems; and (2) providing teachers with guidance for how to facilitate student-centered learning to maximize student understanding. This paper provides criteria—endorsed by the four states and their partners—that are expected to be found in high-quality instructional materials that support the complex teaching and learning required by the Next Generation Science Standards.

Introduction

In 2013, Achieve, Inc., released the Next Generation Science Standards (NGSS), a new set of science education standards based on years of research on how students best learn science and guided by input from classroom teachers, education researchers, scientists, and higher education professionals. Since their release, 18 states (including California, Nevada, Oregon, and Washington), the District of Columbia, and the territory of Guam have adopted the NGSS. As states begin to implement the standards, educators are gaining an appreciation for the complexity and richness of the NGSS, the instructional shifts that are required to facilitate student understanding and learning, and how to uphold the vision of *All Standards, All Students* (see Appendix D of the NGSS). These same educators are recognizing the importance of high-quality instructional materials for the full implementation of the NGSS.

The purpose of this white paper is to emphasize characteristics of instruction and resource materials that are critical for teachers engaging students in high-quality science instruction to meet the full vision of the NGSS. The characteristics, conclusions, and recommendations presented in this paper represent the voice of science teachers in our respective states (California, Nevada, Oregon and Washington) and are informed by our state experts who have been implementing the NGSS, along with input from references that helped develop our understanding of the vision and intent of *A Framework for K–12 Science Education* and the standards themselves (NGSS Lead States, 2013).

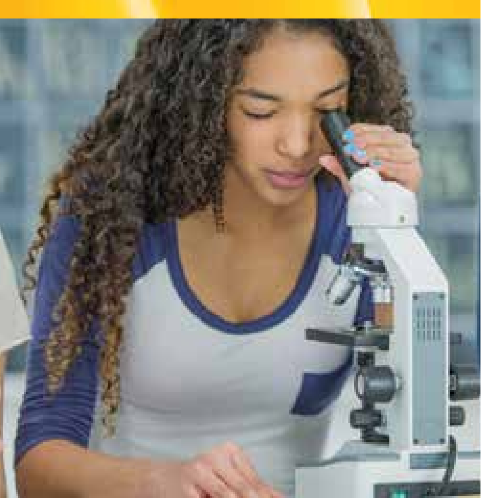
Summary of Recommendations

Our goal is to ensure equitable access for all students to see themselves as a part of the scientific enterprise, to experience science as a human endeavor, and to understand the value of science for making sense of their world. High-quality instructional materials play a vital role in achieving this goal.

Instructional materials must have coherence in design and support equitable access to meet the diverse needs of every student. This coherence of instructional materials and their multiple components is paramount to student success. One mechanism to enable this is to understand and address student preconceptions while valuing their insights, perspectives, and experiences to help frame and build new knowledge constructs (NRC, 2000, pp. 14-15) (Schwarz, Passmore, & Reiser, 2017, p. 33-34).

To fulfill the vision of *All Standards, All Students*, instructional materials must support the shifts towards more equitable, active, and engaged learning for all students. Instructional materials should provide specific supports for instruction that is appropriately rigorous and challenging, and structured in such a way as to provide equitable access to meet the diverse needs of every student regardless of background or learning characteristics. These supports must ensure that science is an intellectually rich, relevant, and engaging experience for all students while leveraging the unique perspectives and assets of students. (CDE, 2016, Ch. 10, pp. 3-5; Schwarz, Passmore, & Reiser, 2017, p. 33-34).

Additionally, a logical progression of each of the three dimensions of learning—Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts—of the NGSS is necessary to build coherence for deep understanding of phenomena focused on the natural and human-built world; including how each impacts the other. Learning must be anchored in phenomena and problems that are appropriate for students, drive learning, and allow for scientific understanding to build over time. Multiple opportunities must be provided for students to express their understandings of the phenomena and problems under study in various formats. Materials should not only support a three-dimensional approach to learning in which students utilize Science and Engineering Practices and apply Crosscutting Concepts to understand Disciplinary Core Ideas, but they should also engage students in iterative sense-making as scientists do.



Instructional materials should support a classroom assessment system aligned with experiences in the text, auxiliary information, and supports for the needs of students. This must assess students in all three dimensions (including the nature of science), move students toward demonstrating application of knowledge instead of memorization of facts and vocabulary, and be useful in guiding instruction. Instructional materials also need to support the full intent of course models with partial or full integration of science.

Finally, there is a very great need for materials to prepare students for a technologically rich future by supporting the full intent of two key Science and Engineering Practices—Analysis of Data and Mathematics and Computational Thinking—and their connection with other practices.

Recommendations

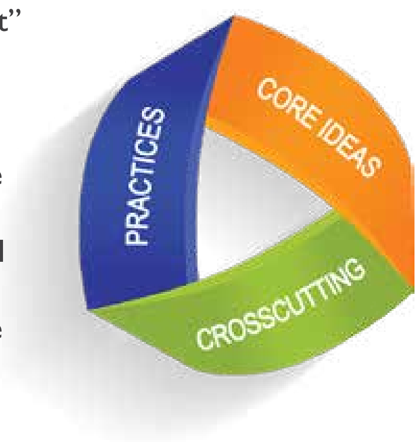
To fulfill the expectations envisioned in the NGSS, with full engagement of students in science, the following aspects must be incorporated into instructional materials as outlined and discussed below.

Three Dimensional Learning

Learning and doing science requires complex thinking, thus the three dimensions of Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs), should not be presented as separate entities but must be integrated together in instruction and assessment (NASEM, 2017, p. 9).

Instructional materials should provide consistent opportunities for students to routinely use Science and Engineering Practices and apply Crosscutting Concepts as primary tools to engage in sense-making and deepen their understanding of core ideas. In other words, SEPs and CCCs are used as a means for students to build Disciplinary Core Idea knowledge (NRC, 2012, pp. 8-9).

All three dimensions are considered "the content" that students need to build increasing depth and proficiency in over time. Instructional materials must support multiple opportunities to use and increase the sophistication of knowledge and use of each CCC and SEP throughout the course of instruction (CDE, 2016, Ch. 13, p. 8). Instructional materials must also build understanding of multiple grade-appropriate elements of the three dimensions in a grade-appropriate context of explaining phenomena or designing solutions to problems (Achieve, EQuIP Rubric, 2016).



Phenomena and Problems

Instructional materials should focus on explaining phenomena and/or engineering solutions to solve problems and constitute the central reason students engage in three-dimensional learning (Achieve, Using Phenomena, 2016, p. 2; NGSS Lead States, 2013, App. I).

Instructional sequences should begin with a phenomenon or problem, build understanding over time, and come to closure at the end (CDE, 2016, Ch. 13, p. 11).

Instructional materials and resources should provide for the possibility of substituting phenomena of a more local context to accommodate for student perspectives and engagement. Examples of these include phenomena around observable components of the students' school or community, local environmental issues, etc. (Achieve, Using Phenomena, 2016, p. 2).

Instructional materials should provide opportunities for students to solve meaningful problems through engineering in local contexts. This allows diverse students to deepen their science knowledge, come to view science as relevant to their lives and future, and engage in science in socially relevant and transformative ways (NGSS Lead States, 2013, App. I, p. 2).

Instructional materials should provide real world phenomena and problems that are used to drive instruction and support a coherent storyline. Students engage in the SEPs and CCCs as a way of answering questions that arise from the study of phenomena or to design solutions to real world problems, thus deepening understanding of targeted DCIs (CDE, 2016, Ch. 13, p. 11).

Phenomena or problems presented to students must be from our natural or human-built world (including, when appropriate, where they intersect), observable to students, developmentally appropriate, relevant, and interesting to students, thus providing opportunities for students to investigate, model, and explain thinking orally and in written form with evidence and reasoning. They must be explainable or solvable using targeted, grade-appropriate DCIs, SEPs, and CCCs and not just attention-getters but drivers of learning (CDE, 2016, Ch. 11, pp. 8-11).

Part of the learning process in deepening the understanding of DCIs is how students practice modeling as it pertains to phenomena. Students are expected to construct and revise models based on new scientific learnings to predict and explain phenomena and to test solutions using core ideas. Taking part in SEPs like Developing Models provides students the opportunity to practice science and engineering that mirrors the science community's work and thinking. Instructional materials should support this. (Krajick & Merritt, 2012, p. 7).

The iterative cycle of design should be reflected in instructional materials as it offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices. When designing solutions to a problem, engineering DCIs must be integrated with developing DCIs from physical, life, and/or earth and space sciences (NRC 2012, pp. 201-2; Achieve, EQuIP Rubric, 2016).

Student Engagement and Sense-Making

Instructional materials should provide learning experiences that connect with the interests and experiences of students in order for students to effectively build knowledge (NRC, 2012, p. 28). Instructional materials should support this and allow for flexibility in students' pursuing learning objectives that expand entry points for student engagement. Whenever possible, students' learning experiences should be first-hand (NASEM, 2017, pp. 17-18).

Instructional materials should also provide many opportunities for student-driven inquiry. Although scientific ideas (DCIs) may be "known" to the education and scientific communities, they are not necessarily "known" by the student, since this knowledge develops over time. Effective instructional materials support students using what they do know and engaging in productive struggle—testing and re-evaluating their ideas—in order to build scientifically aligned understanding of the DCIs. This complements how scientists come to "know" (through use of SEPs and CCCs). Thus, what happens in K–12 science classrooms will mirror what happens within the scientific community: Sense-making, or making sense of the world, as the fundamental goal of science (Schwarz, Passmore, & Reiser, 2017, p. 6; NASEM, 2017, p. 12).

The focus of instruction must be learner-centric. To support this, materials should support discourse and the types of conversations that students need to support their sense-making and engagement in science. Materials also should support student use of the SEPs and CCCs to provide the context and substance to engage in these discussions and sense-making opportunities. Scientific knowledge is revised and clarified in light of new information, and instructional materials should allow space for students to revise their own thinking with new evidence and discussions and insight about scientific ideas (DCIs) (CDE, 2016, Ch. 13, p. 11).

Further, materials should support opportunities for students to engage in the social negotiation of ideas and consensus building about scientific ideas through the development of evidence-based models and explanations and obtaining and communicating information and engaging in argumentation, as well as the use of Crosscutting Concepts to frame and evolve their thinking (CDE, 2016, Ch. 13, p. 10).

Assessment Systems

Instructional materials should include both summative and formative assessments that are aligned with the three-dimensional sequence in the instructional materials. Assessments should require students to engage in the SEPs and CCCs to demonstrate and apply their understandings of the DCIs; they should be woven together in a way that builds cumulatively, and this should go beyond the text-dependent practices of communicating information and writing explanations (CDE, 2016, Ch. 13, pp. 8, 13; NASEM, 2017, p. 23).

Both formative and summative assessments included with instructional materials should provide teachers sufficient information to see where students are on a continuum including students' prior knowledge and preconceptions and to use the results to guide instruction in all three dimensions (CDE, 2016, Ch. 13, p. 13; NASEM, 2017, p. 49).

Materials should provide support for teachers to target Performance Expectation (PE) learning goals as described in the NGSS Evidence Statements, in order to lead *"All students to become proficient in all grade level PEs."* Instructional materials for assessments need to be three dimensional with all three strands intertwined, rather than isolated (taught or assessed individually), and reflect the connected use of different SEPs, CCCs, and DCIs (CDE, 2016, Ch. 13, p. 11; NRC, 2014, pp. 2-4).

Materials should provide support for multiple and varied assessment opportunities to support student sense-making related to the target phenomenon or problems with explicit formative opportunities, such as teacher questioning strategies, use of student notebooks, and iterative assessment tasks tied to various practices (e.g., explanations, models, etc.), to assess students' knowledge and skills, promote student-to-student discourse, and guide student learning (CDE, Ch. 13, p. 11; NRC, 2014, pp. 2-4).

Integrated Science

Districts in our states will be considering different course models, some of which can be defined as partially integrated (two domains of science) or fully integrated (life, physical, and Earth and space science). To support these models, and the intent behind them to help build scientific literacy, materials should support student understanding of how scientists think and their capacity to see the interconnectedness of science across disciplines and contexts. Students will apply this type of thinking to global challenges they will face as adults (NASEM, 2017, p. 5).

For any integrated course, either partial or full, the expectation is that students will actively engage in linking and applying information across relevant and appropriate science domains to make sense of phenomena. There is a significant difference between this approach and a coordinated approach in which students engage in all domains in silos within the same school year (e.g., Unit 1: Life Science, Unit 2: Physical Science, Unit 3: Earth & Space Science). Instructional materials need to take this dichotomy into consideration.

A modular approach to materials may lend itself to both a discipline specific model and a coordinated approach; however, if the modules themselves are domain specific, the lack of integration within this approach makes it difficult to effectively reach the level of integration required in a truly integrated model. Domain-specific modular instructional materials intended to be multi-purposed for discipline-specific, coordinated, and integrated models will need to provide additional support for teachers to develop coherent, relevant, and authentic integrated units using the modules (Sherriff, R., 2015; CDE, 2016, Ch. 5, pp. 10-11).

Support for Analysis of Data and Mathematics and Computational Thinking

"Just as new science enables or sometimes demands new technologies, new technologies enable new scientific investigations, allowing scientists to probe realms and handle questions of data previously inaccessible to them" (NRC, 2012, p. 32).

Instructional materials should make strong connections to other disciplines such as mathematics and they should also support student proficiency in all Science and Engineering Practices (SEPs). Two of the eight practices have particularly strong connections to mathematics: Analyzing and Interpreting Data and Using Mathematics and Computational Thinking. Preparing students for a technologically rich future will require material developers to employ a novel vision in creating materials around these practices. Furthermore, the development of materials for *all* SEPs will require such vision in order to support student growth in understanding and the use of the practices.

Materials should help students understand that they engage in multiple practices when Analyzing and Interpreting Data. Materials should routinely relate Mathematics and Computational Thinking to other SEPs, especially the strong connections with Analyzing and Interpreting Data, Developing and Using Models, Engaging in Argument from Evidence, and Communicating Information (Krajcik, J., 2011, p. 8; Schwarz, Passmore, & Reiser, 2017, pp. 159-204; CDE, 2016, App. 3, pp. 2-4).

Instructional materials supporting the SEPs should provide students with multiple supported opportunities to work with raw data to identify and explain connections and support claims between their questions and the problems they are trying to solve. Whenever possible, this data should be collected first-hand by students as a part of Planning and Carrying Out Investigations. As we enter into a world of information, students must gain the scientific literacy that involves analyzing data to make decisions about which data are useful and could be used for identification of patterns, relationships, trends and anomalies. Students should be making decisions about how to represent data (visualization tools such as tables, graphs, or diagrams) to make it easier to identify these features and for communicating with others. Students should be routinely engaging in sense-making, collaborating, and revising their thinking when working with data as they attempt to answer questions about phenomena and solve problems (Schwarz, Passmore, & Reiser, 2017, pp. 159-180).

One of the hallmarks of the NGSS is that they require instructional materials to provide explicit alignment with other grade-appropriate content standards, support student connections between these and the science ideas they are exploring, and provide ample student-centered opportunities for student sense-making and critical reasoning, including the extension to new ideas to make predictions or comparisons when age appropriate. Age-appropriateness must be reflected in the phenomena the mathematics is being applied to (tangible, small scale macro-phenomena in lower grades becoming more complex, relationship-dependent, and abstract in upper grades), type of data analyzed (qualitative in lower grades becoming more quantitative in upper grades), and ways of analyzing data (descriptive in all grades, but allowing for the ability to generalize relationships by middle and high school with those relationships becoming more complex with older students, and the use of more sophisticated and precise tools and statistical analyses in upper grades) (NGSS Lead States, 2013, App. F, p. 9; Schwarz, Passmore, & Reiser, 2017, pp. 159-180).

In addition to supports for analyzing qualitative data, materials should support student identification of appropriate tools and computational techniques to help students answer their questions. This will provide a bridge between traditional quantitative data collection and new measuring devices or techniques and help students understand what the new device or tool measures and/or how it functions.

Leveraging technology is essential in implementing the NGSS, especially in the Analysis of Data and Mathematics and Computational Thinking. When appropriate, computers and digital tools can provide an augmentation of mathematics by automating calculations, yielding approximations, and analyzing large data sets to identify meaningful patterns or anomalies. As proficiency is gained in the practice over time, students should not just be using tools that already exist but building their own as they abstract information from the real world into a model. In this case, students should utilize, modify, and develop simulations that represent what they are studying as a mechanism to dig deeper into computational thinking practice, to reveal patterns that enable predictions, and to allow for calibration of the simulation to improve reliability as they account for limitations (NGSS Lead States, 2013, App. F, p. 10; Schwarz, Passmore, & Reiser, 2017, pp. 181-204; CDE, 2016, App. 3, pp. 2-8).

NGSS Shifts Call for Educative Curriculum

Teachers will need assistance in making the shifts to NGSS instruction. Educative curriculum materials have the potential to provide job-embedded professional learning experiences as they progress in their ability to implement full NGSS instruction (Davis, et al., 2017). Educative instructional materials have design features that promote teacher and student learning, including pedagogical content knowledge in three-dimension learning, pedagogical content knowledge in scientific inquiry, and subject matter knowledge (Davis & Krajcik, 2005).

NGSS-aligned instructional materials should align to the design heuristics of educative instructional materials including,

1. engaging students with topic-specific scientific phenomena;
2. using instructional representations that support student understanding;
3. anticipating, understanding, and dealing with students' ideas about science;
4. engaging students in questions;
5. engaging students with collecting and analyzing data;
6. engaging students in designing investigations;
7. engaging students in making explanations based on evidence; and
8. promoting scientific communication.

Ensuring that educative materials support teachers as they create NGSS-aligned classrooms is critical for the success of full implementation. The emphasis should be in helping teachers recognize the importance of students' ideas and providing insight into what ideas from students will be likely within a topic and how teachers might deal with student ideas in their classroom, for example, by giving suggestions of thought experiments likely to promote the development of more scientific ideas (Davis & Krajcik, 2005).

> Our Associations are focused on advocating for high-quality coherent resources and instructional materials to support teachers in full implementation of the NGSS. We firmly believe that carefully planned and well-designed materials are critical components for our students and teachers to reach the full expectations and vision of the NGSS. We stand ready to support publishers in the endeavor of designing and developing the necessary instructional materials.

Supporters

In addition to the California, Nevada, Oregon, and Washington Science Teachers Associations, the following organizations and individuals have reviewed and support the recommendations in this white paper:

California Science Project

Children Now

Code.org

California Curriculum and Instruction Steering Committee (CISC) – Science Subcommittee

Helen Quinn, Chair, National Academy of Science's Board on Science Education (2009 - 2014); Co-Chair, California Framework and Evaluation Criteria Committee for Science (2014 - 2015); and Professor of Particle Physics and Astrophysics, Emerita, at SLAC National Accelerator Laboratory

K-12 Alliance @ WestEd

National Science Teachers Association

Nevada STEM Coalition

Ten Strands

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