Introduction

OpenSciEd instructional materials from kindergarten through high school are thoughtfully constructed with multiple familiar considerations and constraints in mind, such as standards, scope and sequence, an instructional model, and pacing. Yet, these elements are not enough. Instructional materials must convey a classroom vision that is inclusive of all learners and creates an image of how students will engage with the content, what type of discourse students will engage in, and a sense of what a teacher needs to make that vision come alive.

As an organization, OpenSciEd is committed to acknowledging and taking on inequities in education. As science educators, we endeavor to develop science instructional materials that provide equitable learning opportunities for historically disenfranchised students. OpenSciEd’s beliefs about science learning and vision of the classroom are embodied in our design specifications. These sixteen specifications describe what we want science learning to look like for every student, and therefore guide our materials development process and implementation support. The topics addressed range from equitable science instruction and the centrality of asking questions, to meeting practical needs and constraints of a classroom. These specifications are based on A Framework for K-12 Science Education and the resulting Next Generation Science Standards, including the emphasis on three-dimensional learning.

On the following pages are detailed descriptions of each design specification:

1 – Instructional Model
2 – Equitable Science Instruction for All Students
3 – Classroom Culture
4 – Supporting Multilingual Learners
5 – Assessment to Inform Teaching and Learning
6 – Designing Educative Features
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1–Instructional Model

Instructional materials provide a coherent path anchored in students’ own experiences and questions to build disciplinary core ideas and crosscutting concepts through an iterative process of questioning, investigating, modeling, and constructing explanations. Students experience learning as meaningful (making sense of ideas rather than just reproducing them), cumulative (learning challenges require them to use and build on what they figured out in previous lessons), and progressive (the class improves explanations or solutions over time by iteratively assessing them, elaborating on them, and holding them up to critique and evidence).

1.1. Units are organized into a coherent storyline.

In a coherent storyline, the flow of lessons makes sense from the students’ perspective as it builds toward three-dimensional performance expectations.

1.1.1. Units are organized as a sequence of lessons designed to build toward three-dimensional learning targets based on the Next Generation Science Standards (NGSS) performance expectations (PEs). This could be done in a variety of ways, including the bundling the PEs or developing unit level three-dimensional learning goals using the elements of the NGSS. It will be clear to educators who are evaluating or using OpenSciEd elementary school materials which aspects of the PEs are learning targets for each unit and course. The sequence of K-5 units will build towards all of the NGSS elementary PEs. The logic of the sequence should reflect a storyline that makes sense to students, where each lesson is motivated by questions students generate in order to explain phenomena, and in the case of engineering design units, to solve a problem. Questions come from the original anchoring phenomena or challenge and from new puzzles that arise as students make progress on their models, explanations, or solutions.

1.1.2. The overall instructional flow of a unit involves a series of lessons that guide teachers and students to work together to establish the driving question for the unit; put together a sequence of investigations to develop portions of science ideas and/or design solutions; and put these elements together to develop a model that can be used to explain the phenomena or solve the problem. The lessons support ongoing reflection and navigation discussions in which teachers and students evaluate their progress and determine next
steps. The sequence culminates with students putting pieces of what they have learned over the course of the unit together to explain the anchor phenomenon or the design of a solution. This should compare competing possibilities and assemble elements of a model, an explanation, or design solution developed across the unit and evaluate its completeness, which may lead to additional cycles of further questions and investigation.

1.1.3. Each lesson has a clear goal, explicit for students, of improving some part of a model or explanation for phenomena, and/or contributing to the solution of a problem.

1.1.4. Each lesson is designed to enable students to make progress on their questions by using science and engineering practices and crosscutting concepts to help figure out a part of a science idea or make progress on solving an engineering design problem. Each idea they develop in greater depth adds to the developing explanation, model, or design solution. Each step may also generate new questions that add to students' work in the unit.

1.1.5. To support the flow of the storyline, each lesson contains guidance for teachers to co-construct the framing of the lesson with students so it builds toward the target performance expectations and clearly links to what students have identified in prior lessons as areas to extend or questions to address. The framing involves both the focus of the work (questions to address) and the way the class will make progress (e.g. develop new hypotheses, test ideas through investigation, argue with evidence, revise explanations, represent and compare ideas, evaluate and compare competing design solutions).

1.1.6. Instructional materials use a consistent structure for units, consisting of a four-level hierarchy (units made up of lesson sets, sets made up of lessons, lessons made up of activities) with information provided to teachers at each level.

An example of a coherent storyline might be one in which students work with various living organisms (butterflies, mealworms, beans) to observe their life cycles and develop models to describe that organisms have unique and
diverse life cycles but all have a common pattern of birth/seed, growth, reproduction, and death.

A non-example is a series of life science lessons (butterfly cocoons, mealworm larvae, sprouting bean seeds) that all are related to a broader topic (life cycles) by highlighting one aspect of a specific species’ life cycle, but do not explicitly help students construct the knowledge needed to recognize the pattern of a life cycle and how that pattern repeats among a diversity of organisms.

1.2. Student sensemaking of anchoring phenomena and solving of design problems drives the units.

Learning is motivated by attempting to make sense of initial phenomena or problems students identify related to the science learning targets, leading to iterative cycles of investigating phenomena, improving explanations, models, or designs with new evidence, and further questioning.

1.2.1. Students’ experience with the anchoring phenomena (or the unit problem, in the case of design problem-based units) drives the work of the unit. An anchoring phenomenon is an occurrence in the world that raises questions for students about how and why this event happens, or pose challenges for designing a solution to a problem. Investigating their questions or developing design solutions for the problem provide a context and motivation for students to figure out the target science ideas, and build a shared mission that a classroom learning community needs to figure out phenomena or solve a design problem. The anchoring phenomenon grounds student learning in a common experience and then uses that experience to elicit and feed student curiosity, which then drives learning throughout the unit. For further support, please see the document *Using Phenomena in NGSS Designed Units and Lessons* (Achieve, Inc., 2016).

1.2.2. Students’ experience of the anchoring phenomenon includes several essential elements (order may vary):
   a. Students encounter and explore a phenomenon or problem as directly as possible—in a way that enables them to experience the intriguing nature of the phenomenon or problem and to publicly, as a
learning community, acknowledge aspects of the phenomenon that require explanation or pose the need for a solution.

b. Students attempt to make sense of the phenomenon or problem in a way that enables them to see what is important and difficult to explain, or aspects that are problematic and require solutions, and to generate questions that will guide future investigations or designs.

c. Students are supported to connect their prior knowledge and experiences to the anchoring phenomenon or problem in order to broaden the scope of what the class is interested in figuring out and for students to have a personal connection and investment to the events being explored.

d. Students generate questions about the anchoring phenomenon or problem and work together as a class to refine them. They also generate ideas for how to answer those questions or generate solutions through investigations and designs they will conduct as part of the unit.

1.2.3. Instructionally productive anchoring phenomena have these characteristics:

a. Anchoring phenomena are observable events that occur in the natural or designed world and that we can use our science knowledge to explain or predict. They are not topics, themes, or engineering challenges used to organize a unit. For example, instead of simply learning about the topics of photosynthesis and mitosis, students should be building evidence-based explanatory ideas that help them figure out how a tree grows.

b. Anchoring phenomena require students to draw upon a range of science concepts and ideas and engage them in a number of investigations to build knowledge or solve a problem.

c. Anchoring phenomena or problems are set in contexts that are relevant to students' interests, identities, cultures, and/or lived experiences, so that students' background knowledge and frames of reference are assets for their sensemaking work.

1.2.4. Units that emphasize the design process also begin with anchoring phenomena. Problems that require solutions should arise from phenomena, and students should use explanations of phenomena to design and/or evaluate solutions.
1.2.5. Anchoring phenomena are augmented by other phenomena during the unit. They provide the initial focus for what needs to be explained or solved over the course of the unit. As students make progress, partial models lead to new questions, which motivate bringing in additional phenomena that can help make progress on these questions. A single phenomenon doesn’t have to cover an entire unit, and different phenomena may take different amounts of time to figure out. As students figure out additional phenomena, they should apply this new understanding to better explain the anchor phenomenon.

1.3. Learning as a classroom community is supported through a flow of activity that includes individual, pair, small group, and whole group discussion.

Students are explicitly positioned as collaborators, not competitors, who work as a community to figure something out about the natural or designed world. To enable access and participation for all students, lessons lead up to argumentation, explanation, and modeling in whole group contexts by providing opportunities for students to work out their thinking and talking in individual, pair, and small group contexts prior to whole group discussions. See Chapters 3 and 4 for more specifics about creating a classroom culture that supports language use and the development of argumentation.

1.3.1. Tasks are set up for students to engage in the science and engineering practices through a balance of individual or pair work, small group work, and whole class work.

1.3.2. Key steps in figuring out phenomena and solving problems require involvement of the learning community. Classroom routines support students in the work of scientific argumentation, sharing and comparing their ideas, and negotiating consensus in order to identify questions, develop plans, and revise explanations, solutions, and models. Learning sequences should culminate in lessons specifically focused on evaluating alternatives, engaging in scientific argumentation, and building consensus.

1.3.3. Units support students in participating in the learning community through a sequence that provides time for individual work, pair work, small group work, and engagement in whole-group discussion. This allows students to develop their initial ideas by sharing and listening to others, and receiving and giving
feedback, providing less stressful opportunities to build the confidence necessary to engage in whole-class discussion.

1.3.4. Engaging in science and engineering practices focuses on sharing, critiquing, defending, and negotiating ideas. Units provide supports for students to share their ideas through words and pictures and make their ideas public so that the full community can have access to them. Instructional materials contain opportunities for students to see and engage with each others’ ideas. Supports include general pedagogical approaches such as think-pair-share or jigsaw, and science-specific activity structures, such as gallery walks, driving question boards, or summary charts.

1.3.5. Instructional materials provide support for students to engage in scientific discourse and to learn the use of scientific representations to support this collaboration.

1.3.6. Units support both individual representation of the ideas by students in their notebooks and in public representations of the class consensus on what they have figured out together. Individual and public artifacts keep track of the class questions, their plans, and their progress on models, explanations, and designs. Individual work provides the resources for group and whole-class work, and provides space for students to develop, document, and apply their understanding. Both individual and collective work is central to documenting and guiding progress. Note that in the context of learning science, students engage in consensus process discussions to figure out where they agree and disagree with regard to the meaning of the evidence they have gathered. This process supports students as they iterate on a collective model that shows where they are in agreement at the current moment - while highlighting and valuing the places they don’t agree. “Consensus” should not be misconstrued as being equivalent to unanimous agreement.

1.4. Students engage in incremental revisions and synthesis of ideas.

Supporting three-dimensional learning is an incremental process. Developing explanatory ideas requires figuring out pieces of ideas and then assembling them into more complex explanations, models, or designs, developing intermediate models or designs that are
partially successful, and providing opportunities for students to revise and improve those ideas.

1.4.1. Teacher materials provide guidance for teachers to work with students to incrementally develop, test, critique, and refine explanations and models over the course of a unit. Identification of needed revisions in models may arise from the introduction of new phenomena, classroom argumentation as part of building and evaluating models, new evidence, new investigations students ask to conduct, and new evidence from readings.

1.4.2. Each unit includes multiple opportunities for students to synthesize ideas they have developed across multiple lessons into a coherent, grade level-appropriate model, explanation, or design.

1.4.3. Lessons ask students to share knowledge products that depict their current thinking: models, conceptual drawings, lists of hypotheses, partial explanations, or designs. Students’ representations are referred to as “works in progress” and lessons support students in critiquing and revising these ideas over the course of the unit.

1.4.4. Lessons make coherent connections to preceding lessons to enable the synthesis and revision of ideas. Lessons include planned discussions in which teachers guide students to articulate the current state of the class’ explanations, models, or designs, and identify pending questions to resolve, in order to connect the current lesson to the past work.

1.5. Units fit into the scope and sequence with explicit connections.

Units are designed to support a coherent learning experience. Each unit builds explicitly on the elements of disciplinary core ideas, practices, and crosscutting concepts that have been established in earlier units.

1.5.1. Teacher materials contain explicit connections for teachers to help students build on the disciplinary core ideas and crosscutting concepts established in prior units. Where connections are identified in the scope and sequence between two performance expectation bundles, the unit reflecting the later bundle includes early lessons in which teachers work with students to
explicitly identify relevant elements of disciplinary core ideas and crosscutting concepts from prior work that can help partially address the anchoring phenomena or problem. Students also bring in ideas established in earlier grades, when applicable. The modeling, explanation, and design work builds explicitly on the earlier ideas students have identified.

1.5.2. Instructional materials contain explicit connections for teachers to help students access and build on the science and engineering practices and crosscutting ideas established in prior grades (when applicable) and in prior units. While students are engaging in all three dimensions K-5, their progression not only builds through their explanatory power of the disciplinary core ideas, but also in their ability to flexibly use the science and engineering practices and crosscutting concepts to develop grade-appropriate explanations of phenomena, even if they have encountered similar events in prior units. Lessons guide teachers and students in identifying how they have engaged in the practices in prior units or grades, and build in grade-appropriate advances in the unit.

1.5.3. Teacher materials provide specific guidance on how to follow up on and connect to students’ findings, ideas, and questions raised in the assignment to subsequent discussions in future lessons. Example “alternate prompts” and “expected students responses” are included to help students make connections for cases where the class or student didn’t complete the assignment.

1.6. Instructional materials include support for continuing to learn beyond the classroom and bring experiences from home to the classroom.

1.6.1. Instructional materials include explicit links to follow up ideas, phenomena, and activities that can be done at home or discussed at home. Home connections may also include sample letters to send to parents/guardians as units begin or when anchoring phenomena are introduced.

1.6.2. The purpose of home learning is to provide students opportunities to learn more about how science ideas developed in class can be used to make sense of additional phenomena and problems in their lives and in their communities; to provide new contexts for students to extend their interest,
curiosity, and creativity about what they have figured out in class; and to provide a venue for students to engage in discourse with other people in their lives about what they are wondering, thinking, and figuring out related to the experiences in the classroom.

1.6.3. The structure of home learning opportunities might include framing around a small number of compelling questions, relevant connections to real-world examples, protocols for students to engage in or to explore additional phenomena first hand, concise background information and text, simplified (but not oversimplified) data and protocols, scaffolds for supporting the development of student thinking across an assignment around one big idea, prompts designed to help student raise new questions (leaving them more curious at the end of the assignment than when they started it), and suggestions to help spark student interest in initiating or participating in a conversation about what they are doing or figuring out with other people.

1.7. Engineering practices are used in units when it furthers the science.

Units use science and engineering together when appropriate. When engineering practices are included, those practices also help students deepen the relevant science.

1.7.1. Units include engineering practices when they can deepen science learning. Engineering practices are always paired with disciplinary core ideas from life, earth and space, or physical science. Engineering practices are not used just in combination with engineering disciplinary core ideas, that is, solely to learn about the nature of engineering.

1.7.2. Engineering design problems provide opportunities for students to deepen their explanations and models of scientific phenomena. Engineering design problems do not simply draw from and ask students to apply science that students have already learned, or if students are able to use trial-and-error to find a solution to the problem, without drawing on science ideas for their solution.
2–Equitable Science Instruction for All Students

In developing instructional materials today, we must recognize the vast range of student diversity in today's classrooms and honor the cultural and linguistic assets that students bring, while acknowledging the deep injustices in society. Therefore, instructional materials need to build on the guidelines in *A Framework for K-12 Science Education* and the *Next Generation Science Standards* (NGSS) to support learners who come from non-dominant communities or are underrepresented in non-required STEM classes, college majors, and careers. Instructional materials guide teachers in implementing equitable science instruction for all students, and are flexible enough to be adapted to fit teachers' and students' local circumstances. The practices described in the equity design specifications are central to science teaching and learning everywhere and for all students; they are not add-on strategies that only need to be deployed in the presence of students from historically underserved communities. Professional development that supports implementation of the instructional materials must focus on these equity practices.

Equity Design Stance: Instructional materials 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, including scales related to race, socioeconomic class, gender, educational sovereignty, Indigenous rights, immigration history, land and water rights, sexual orientation, gender expression, abilities, and other dimensions of social difference related to justice. From a critical historical perspective, working toward equity and justice involves implementing approaches that de-settle inequitable systems, routines, and assumptions that are likely to be in place in many educational institutions. In coordination, it is then possible to support expansive cultural learning pathways for youth working from an asset perspective. In particular, these pathways should be designed to center the lifeworlds of non-dominant communities in support of multiple ways of knowing, being, and valuing. As detailed in *A Framework for K-12 Science Education*, all science learning is a cultural accomplishment.

Additionally, instructional materials are designed to follow principles of the *Universal Design for Learning (UDL)*: Provide students with multiple means of engagement, representation, and expression; leverage students’ sensemaking repertoires to support three-dimensional learning; and support peer interactions that enable active engagement in investigation-based science learning.
Diverse Design Teams: To design for equitable instruction, instructional designers need to acknowledge and account for the design bias that relates to the cultural diversity and history of their team. Teams should include designers from a range of experiences and backgrounds, or recruit consultants who can attend to issues that arise from homogeneity and socially dominant positioning, in order to better de-settle oppressive curricular representations and pedagogical practices. Design teams should include designers who reflect the experiences along race, ethnicity, culture, gender, class, and/or ability of the students who will learn with the OpenSciEd instructional materials. While it may not be possible for design teams to include members that identify with all of these identities, it is important for designers with (some of) these experiences to be present throughout the work at all times, rather than brought on only as special consultants to review the work produced by designers who identify with dominant groups. Many of the design recommendations depend upon the instructional design knowledge of people who have specific equity-focused expertise—such individuals will need to be meaningfully integrated into design teams in order to attend to equity and justice in the design of instructional materials.

2.1. Diversity is made visible.

Individuals, teams, and communities from all nations and cultures have contributed to science and to advances in engineering—across differences of race, ethnicity, gender, and abilities. Instructional materials have a broad range of images and stories of who does and has done STEM endeavors in our society (through inclusive storylines, phenomena, sustained examples), and highlight the broad range of purposes for STEM endeavors (focusing sensemaking on community projects, civic engagement, personal and family pursuits, justice projects, and 21st century global challenges and decision-making, not just STEM-related career possibilities). Design teams consider whose interests are being served by the images of STEM endeavors represented in instructional materials and prioritize the interests of underserved communities.

2.1.1. Instructional materials acknowledge and foreground the specific contributions of members from multiple communities to scientific and technological enterprises related to the topic, practices, and knowledge involved. These accounts are substantial, accurate, and respectful to the originating work and community. Both pictorial and descriptive images of STEM endeavors include diverse images in historical, contemporary, and future-focused terms as appropriate. The diversity of STEM endeavors of
cultural communities are not inappropriately portrayed only as efforts from the past and make visible the diverse forms of STEM efforts that are currently unfolding and evolving.

2.1.2. Cultural and gender diversity is integrated into lessons by carefully weaving together subject matter, corresponding sensemaking activities, and images with relevant sociocultural contexts that recognize the scientific and technological contributions of members from various cultural backgrounds. For example, instructional materials include and clearly highlight the efforts of scientists of all gender identities. Learning experiences are designed to promote a deeper sense of global community, agency, social responsibility and action, rather than using phenomena, settings, or examples that primarily center on the activities or interests of the dominant U.S. culture.

2.1.3. Topics, concepts, and practices within units are related to the backgrounds of students by recognizing that all learners belong to multiple cultural communities that share different practices, purposes, ways of interacting, and approaches to conceptualizing and engaging with the world. Students are able to “see themselves” in the scientific endeavor—as represented through instructional materials—in order for them to feel comfortable engaging in science learning meaningfully.

2.1.4. The dynamic and variable nature of cultural groups is highlighted, including the inherent variations and regularities in cultural practices and values, and how these may change over time. Instructional materials avoid essentializing the activities and qualities of cultural groups and actively work against narrow and uniform (formulaic) ways that science is conducted (for example, by highlighting different forms of argumentation and explanation). Instructional materials do not assume that all learners from a given cultural community engage in similar sensemaking practices, or that certain cultural communities are homogeneous and stable over time.
2.2. Learning experiences focus on youth relevance and community purpose.

Building on the vision of *A Framework for K-12 Science Education*, instructional materials relate to the interests, identities, and experiences of students and the goals and needs of their communities. Instructional materials create opportunities for instruction to be guided by cultural formative assessment strategies and to leverage local funds of knowledge.

2.2.1. Instructional materials create opportunities for teachers to engage in culturally-responsive formative assessment, eliciting and instructionally responding to their students’ prior knowledge, interests, and identities. At key points within each unit after students develop an understanding of an important science idea, a self-documentation instructional technique is used to help students see how the focal science ideas they have learned about relate to everyday phenomena of their lives.

2.2.2. Instructional materials make explicit the importance of identifying the dynamic everyday practices and concerns in the students’ communities that can be meaningfully related to classroom science and engineering investigations. Units explore how anchor or investigative phenomena relate to the interests and practices of the local community or to a shared global concern. The leading activity of units are personally meaningful phenomena, not abstract science ideas, and are sometimes introduced through a cultural launch that locates the anchor phenomena in a context of the community.

2.2.3. Culturally-responsive and sustaining formative assessments support teachers in building on students’ prior interests, identities, and experiences. For example, as students express interests or developing expertise, they should have opportunities to share in ways that highlight their linguistic and cultural assets. Several times a year students should be able to relate science ideas or practices they are learning about and put them into some type of action (such as working as an individual or in a small group to develop a public service announcement that applies science ideas to a specific topic or practice, or working in a small group on a design project that applies science ideas to an authentic problem).

2.2.4. Instructional materials include opportunities for teachers to support students to engage in community endeavors as part of their science class.
Each year there are several culturally meaningful science investigations that occur in the context of the local community (such as a field investigation, design project, or local data collection at a school site). At least two elementary school units per grade level focus on anchor phenomena that can be meaningfully focused in relation to the community (that is, not all units have a fully “pre-packaged” anchor phenomena). This should include taking a place-based science education approach.

2.2.5. Instructional materials include opportunities for students to develop new science-related interests and to learn how they relate to social pursuits in the world. Within each unit, students are given time to document, reflect on, and explore their developing science-related interests, and they are supported to further explore those interests (for example, by talking with an expert or researching different endeavors online or at the library).

2.2.6. Teachers are guided in relating science to the histories, current priorities, and aspirational futures of communities, especially those of local indigenous communities in conjunction with their recognized rights and other groups owed an education debt. This can shape the framing and relevancy of science ideas and practices, the pedagogical approach, the languages used in instruction, and the experts brought in to support science learning.

2.3. Equitable sensemaking is supported in the science classroom.

Creating equitable learning opportunities depends on an orientation that the ideas students raise and the reasoning they use are critical to the sensemaking of science. It is essential that children's contributions not be treated as being off topic or disruptive even when it is not what the teacher expected. Instructional materials enable teachers to recognize and leverage diverse assets and perspectives students bring for making sense of phenomena, and broaden what counts as competency to include everyday and professional forms. Instructional materials actively work against reductive accounts of proficiency (such as privileging prestige English in rubrics or culturally narrow images of the science and engineering practices) and advocate for the use of students' everyday language. They scaffold multiple forms of practice engagements and identify as well as leverage students' sensemaking repertoires, rather than an idealized, dominant form.
2.3.1. Instructional materials cultivate an equitable learning community in the classroom by engaging students in activities that promote trusting and caring relationships, a shared understanding of the cultural diversity of its members, and equity in all sensemaking. Each unit includes a community building exercise or activity that relates to the focus of the unit. Instructional materials emphasize the importance of developing and maintaining equitable learning experiences, particularly by interrogating participation, and by promoting social norms that support safe and fair participation while interrupting cultural norms or stereotypes that could make science experiences feel unwelcome to students who might otherwise feel disenfranchised from science (for example, feeling like someone is not intelligent enough to think like a scientist, cannot do the relevant math, or cannot share their thinking).

2.3.2. Units use Universal Design for Learning Guidelines to ensure all students are positioned to intellectually engage throughout all collaborative sensemaking. See Chapter 6 for connections to UDL in educative curriculum materials.

2.3.3. Instructional materials highlight the importance of not putting students into set roles that are less intellectually engaging, like “materials manager,” and instead use a range of intellectual roles associated with the collaborative learning process (for example, idea connector, causal checker, evidence wrangler, and relevance hunter).

2.3.4. Activities allow for teachers to notice and leverage students’ diverse sensemaking contributions and connect them to the science and engineering practices involved in an investigation. These contributions can relate to styles of speaking or writing, ways of observing and interpreting, forms of reasoning, uses of gestures or movements, or diagrams and other forms of expression. Instructional materials create opportunities for instruction to make room for these different kinds of contributions to all sensemaking activities, rather than expecting students to contribute in narrow or prescribed ways. Teachers receive instructional guidance to leverage the specific contributions of individual students and make direct connections to science, rather than lightly polling (or “popcorning”) across the classroom community.
2.3.5. Instructional materials guide teachers in highlighting how students’ community histories, values, and practices contribute to scientific understanding and problem solving. Classes explore how students’ community histories, values, and practices contribute to scientific understanding and problem solving related to the unit investigation.

2.3.6. Instructional materials include a broad representation of how various communities leverage their ways of knowing, ways of talking, and ways of seeing the work for making sense of natural phenomena and solving problems, and avoid causing epistemic injury by communicating that science and engineering practices occur only one way.

2.3.7. Teachers are guided in using embedded cognitive formative assessments to surface and instructionally respond to students’ facets of thinking (the full range of students’ ideas about a topic or concept) throughout the sensemaking process. Students develop these facets of thinking as they experience and make sense of the natural world. Teachers are guided on how to respond to specific ideas from an asset-based perspective (what is appreciated, what is concerning), allowing them to recognize the richness in students’ reasoning and to support students to refine their ideas in a constructive and respectful manner. Facet-based rubrics that account for the diversity of student’s typical thinking are included for assessments integrated in lessons around the learning of difficult concepts. Rubrics do not focus on single-scale learning progressions or only on identifying students’ misconceptions.

2.3.8. Instructional materials create opportunities for students to engage in engineering design practices in culturally meaningful ways, particularly by leveraging elementary students’ everyday experiences and contextualizing design projects to be locally relevant.

2.3.9. Teachers are guided in understanding the importance of navigating within and across multiple ways of making sense of the natural world, such as instructionally centering on the Indigenous Ways of Knowing and Being.
2.4. Participation and learning of multilingual learners are supported.

To support emerging multilingual learners*, instructional materials are designed to support equitable participation in science and engineering practices, in ways that are culturally sustaining; leverage students’ full linguistic repertoires, such as multiple languages and registers; and value and promote multi-modal performances beyond written or spoken forms of expression. Supporting the equitable participation and learning of emerging multilingual learners and all students requires new understandings of the language affordances and demands inherent in science learning. Additionally, this shift requires understanding new strategies for building on the lived experiences and linguistic resources that all students bring to the science classroom. For further guidance on addressing the needs of multilingual learners, refer to Chapter 4 in this document or English Learners in STEM Subjects: Transforming Classrooms, Schools, and Lives.

*Multilingual students are often referred to as “English Language Learners,” but instructional materials should use the term “emerging multilingual students” to acknowledge and value these students’ bi-/multilingualism, bi-/multiculturalism, and highlight that they have a right to learn science content beyond developing English fluency.

2.4.1. Instructional materials clearly state that cultural and professional communities have specialized discursive practices that allow community members participate in meaning-making activities. Specifically, they explain that science and engineering have developed specialized discursive practices that help their members make sense of natural phenomena and solve problems. Several times each year, students have opportunities to identify the similarities and differences between familiar everyday ways of communicating and the specialized ways of communicating of science and engineering (for example, an activity that has students identify the similarities and differences between forms of evidence-based argumentation and forms of opinion-based argumentation). Units make the case for why specialized ways of talking are productive for sensemaking, and should not delegitimize students’ everyday ways of talking.

2.4.2. Instructional materials clearly state that cultural and professional communities have specialized languages (registers) that help community members share their ideas and collaboratively make meaning. Specifically, they explain that it is normal for people to switch or intertwine registers from
different contexts when engaging in sensemaking activities. Every unit creates opportunities for students to engage in register switching along the continuum of everyday language and the specialized language of science and engineering, according to what they find most useful. Units present content and create opportunities for teachers and students to share ideas by leveraging linguistic resources along the continuum of everyday language and specialized language. Activities do not bar students from using everyday language for their sensemaking and communication, especially when this can be a powerful tool for equitable participation. The continuum between everyday and specialized language is available for students to choose from when sharing their ideas and reasoning.

2.4.3. Instructional materials recognize and center students' multilingual and multicultural experiences, highlighting how people around the world engage in science and engineering practices in multiple languages besides English. Units use translanguaging approaches that create opportunities for students to engage in science and engineering practices while fluidly leveraging the multiple languages they speak. Specifically, every unit creates opportunities for teachers to identify, promote, and use the various linguistic resources multilingual students marshal when making sense of natural phenomena or solving problems. An example is an activity where students develop and present forms of evidence-based explanations using their heritage languages or blending the multiple languages they speak. Units do not promote (or connote) English-only instruction, especially in multilingual classrooms.

2.4.4. Activities are included that create opportunities for teachers to leverage what they know about specific students' multilingual and multicultural experiences to help students make personal connections to science content knowledge. Specifically, instructional materials allow teachers to gather information to encourage students to describe times and places where they see the science they are learning in school being used outside of school, and include supports (such as prompts) for teachers to include those understandings into their instructional planning.

2.4.5. Instructional materials focus on more than text-based sensemaking by promoting multimodal communication to support students in making meaning of phenomena or address design challenges. Each unit leverages
multimodal and intertextual approaches to highlight and make visible key ideas. For example, every unit has opportunities for teachers and students to share ideas by using modalities that go beyond speech and written text, such as graphical representations, gestures, onomatopoeias, and embodied representations of key concepts and processes. Instructional materials do not bar students from using multiple modalities for meaning-making, especially when this is a powerful tool for equitable participation. Students are able to use both linguistic resources and multiple modalities when sharing their ideas and reasoning.

2.4.6. Activities are organized in ways that create opportunities for multilingual students to engage in meaningful accountable talk, by emphasizing socially safe and relevant activity structures (such as small-group work before whole-class discussions) and by providing a range of scaffolds for multilingual students to find their way into discussions. For example, at least three times in every unit students have the opportunity to engage in think-pair-share or “idea coaching” structures, and are provided with modalities to support all students in engaging with and making sense of each other’s ideas.

2.5. Participation and learning of special education students are supported.

Instructional materials are designed to follow principles of the Universal Design for Learning: Provide students with multiple means of engagement, representation, and expression; leverage students’ sensemaking repertoires to support three-dimensional learning; and support peer interactions that enable active engagement in investigation-based science learning. Additionally, they create opportunities for students with learning needs to develop self-regulation, self-determination, and agency in order to meaningfully participate in sensemaking activities. From this perspective, equitable instructional materials are designed to reduce barriers that hinder participation and offer students multiple opportunities to engage in deep sensemaking of the natural and designed worlds; instructional materials do not assume that students themselves require modifications and adaptations to meet learning goals. Instructional materials support the creation of learning environments that are more usable, accessible, safer, and healthier in response to the needs of an increasingly diverse student body, which can be achieved in part by avoiding ableist language and depictions of learners.
2.5.1. Instructional materials do not include ableist language that is disrespectful (such as abnormal, crazy, loony, or victim) and are based on the use of these resources from the National Center for Disability and Journalism for more information: Terms to Avoid When Writing About Disability and Disability Language Style Guide.

2.5.2. Instructional materials provide multiple means of engagement to encourage purposeful and motivated three-dimensional science learning:

a. Every unit recruits students’ interest by optimizing individual choice throughout the learning process while engaging students in relevant, rigorous, and meaningful sensemaking. Individual choice extends beyond students choosing their own topic of study or investigation method and includes choices for how students will meet classroom objectives, such as level of perceived challenge of an activity, modes or tools for expressing themselves, and sequence or timing for completing activities. For example, students may be given the choice of different methods to express themselves (such as verbal responses, drawing, acting, or movement demonstration) when presenting information or understanding of what they have learned.

b. Instructional materials guide teachers to organize learning environments in ways that are physically navigable to all students. They sustain learner effort and persistence by making goals and objectives clear, fostering peer collaboration, and building community relationships. Moreover, instructional materials anticipate and list the barriers required equipment may present to students and suggest alternative materials and/or setups.

c. Lessons support students’ self-regulation, self-assessment and reflection create opportunities for teachers to provide performance-based feedback (for example, self-monitoring scaffolds where students can compare their engagement and participation to the expectations of the classroom and unit). Additionally, lessons demonstrate how professional scientists and engineers self-monitor their experiences and self-regulate their responses to challenges that arise during group work, during the iterative processes of design thinking, and/or planning and implementing investigations.

d. Instructional materials guide teachers with general supports and scaffolds that can be used across lessons or units. Teachers can tweak
the general supports to make them better match the lesson (content, types of activities) if desired. For example, providing a “visual task schedule” to help students learn and monitor classroom routines or the steps for completing specific academic tasks that includes visual icons and text for each step in the routine or task. Students refer to the visual schedule and can check off when they have completed the steps in the routine or remove the picture icon from the task schedule.

2.5.3. Instructional materials provide multiple means of representing information and expectations to make the materials comprehensible to learners with learning needs. Every unit supports students to reflect and build on their prior knowledge, and construct generalizable explanations and models.

2.5.4. Instructional materials provide multiple opportunities for students to express their understanding, reasoning, and reflect on their own learning. Every unit includes multiple tools that support students’ engagement with activities and sensemaking (such as investigation materials or assistive technologies), leverages multiple modalities for communicating content and expectations, and provides opportunities for students to express their understanding through multiple modalities (such as drawings or gestures) that leverage and highlight students’ cultural and linguistic assets. Instructional materials make it clear that providing multiple means for expression is categorically different from so-called “learning styles,” arbitrary categories such as “visual learner” and “kinesthetic learner,” which are not scientifically valid and yet prevalent in discussions about learning needs.

2.5.5. Instructional materials create opportunities for students to actively participate in group work and support teachers to set clear goals for activity-driven learning, as well as scaffolds to self-regulate progress in groups and promote students’ agency. Every unit reinforces a positive group-work culture by encouraging students to identify their resources that can strengthen their group, as well as systems to ensure that all students are actively participating in sensemaking. Units include multidimensional, multi-level activities that require the work of all group members to accomplish.
2.5.6. Print and web-based materials will be designed to be products that offer the maximum flexibility of user experience for all readers, allowing the content to be accessed and manipulated with ease by those with or without disabilities. Specifically, instructional materials should account for the following requirements: (1) Structurally tagged content; (2) Text to speech (TTS) capability; (3) Alternative background colors and controllable line spacing; (4) U.S. Department of Education Standards; and (5) Web Content Accessibility Guidelines (WCAG).
Chapter 2 in this document emphasizes equitable science instruction for all students. In this chapter we unpack a key aspect of achieving equitable instruction and the resultant learning by examining the role of classroom culture. Research indicates that a focus on equity aims demands attention to culture, defined as “everyday classroom practices that promote particular meanings of ‘science’” as well as the normative identities developed within that classroom culture. For this document, we are using the definition of a normative identity as the “culturally produced meanings of ‘science person’ and the accessibility of those meanings” (Carlone, et al, 2011). Without conscious and intentional attention to establishing a culture that explicitly names class norms and practices that honor student voice and support identity development, classroom practices function as gatekeepers that prohibit equitable access to high-quality science education.

### 3.1. Creating a Sense of Belonging

In the development of instructional materials, writers should be cognizant of the need to explicitly develop community by including strategies for teachers and activities for learners that establish the learning of science as an inclusive and welcoming opportunity.

- **3.1.1.** Cultivating an equitable learning community in the classroom by engaging students in activities that promote trusting and caring relationships, a shared understanding of the cultural diversity of its members, and equity in all sense making. Promote social norms that support safe and fair participation.

- **3.1.2.** Materials will support a classroom culture where students and teachers act as co-inquisitors whose interests, questions and contributions are valuable for sense-making.

### 3.2. Setting Norms and Expectations

The instructional materials can support the establishment and maintenance of a classroom culture by providing norms and expectations about behavior, social interactions, and competent scientific practice that align with full engagement in phenomena-based science learning and the development of explanations.

- **3.2.1.** Materials offer an introductory component each year that supports the development of classroom norms.
3.2.2. Instructional materials provide supports for teachers to establish clear classroom norms that support three-dimensional learning, including what counts as competent scientific practice (e.g., what counts as a good observation, good explanation, etc), going public with one's thinking, respectfully questioning ideas, listening to others and building on their ideas, continued testing of the generality and limitations of candidate models, and supporting models and explanations with empirical evidence. Considerations and norms for equitable class culture are described in Chapters 2 and 4 of the Design Specifications and should be utilized to create a classroom where all students feel safe in sharing their thinking.

3.2.3. Teachers are guided in developing and maintaining classroom norms that support student engagement in the science and engineering practices through productive talk. In particular, students have opportunities to build on the contributions of others, assume considerable responsibility for the success of academic conversations, initiate topics and make unsolicited contributions. (See the Talk Science research from TERC as one rich example of how to do this.)

3.2.4. Materials support teachers to build “a culture of argumentation in the classroom marked by a shared goal of consensus, achieved through collective norms for persuasion and practices aligned with those norms” (Sandoval et al, 2019). It is essential that argumentation not be treated as a separate skill, but be a fully integrated part of the science culture in the classroom. (See Chapter 9 for more elaboration on argumentation.)

3.3. Leveraging and Sustaining Student’s Cultural and Linguistic Assets

Materials include meaningful opportunities for teachers to draw in and build on student’s experiences, multiple ways of knowing, cultural and linguistic resources, including the practices of their family and community.

3.3.1. Materials include activities that students take home to gather data from their families and community and bring back to the classroom to build a culture in which everyone can access scientific thinking and contribute to the development of ideas.

3.3.2. Materials are available in multiple languages and have been field tested in different language and cultural settings, not translated after the fact.
3.4. Developing a Science Identity

Developing a science identity is key to pursuing science for the long term and is different than being academically successful in science. For example, students can know and do science, but not necessarily see themselves as scientific or affiliated with the normative science identities promoted in the setting. Students of all identities need to see themselves as scientists doing the things that scientists do in traditional and non-traditional settings, if we are going to diversify the workforce and expand scientific literacy.

3.4.1. Materials create opportunities for students to identify when they and others are being scientists and engineers by taking actions such as asking questions about the natural world, identifying problems in need of solutions, making observations, describing things, being persistent when they get something wrong, always thinking of experiments to do and tests to conduct. These practices are accessible to all students, thus broadening opportunities for all students to author themselves and get recognized as being scientific.

3.4.2. Materials offer teachers strategies that support student’s science identity development. The integration of notebook activities that support reflection about one’s identity is especially important for this work.

3.4.3. At the most basic level, the materials portray scientists and science literate individuals working across many contexts—informal and formal settings and include different genders, abilities, as well as people from many cultures and nations, both contemporary and historical. This is necessary, but insufficient, for identity development.

3.4.4. The materials portray scientists and the work of scientists as a human endeavor, including socioemotional aspects of scientific work, such as curiosity, creativity, imagination, teamwork, struggle, surprise, confusion, frustration, pride, wonder, and awe. The materials provide opportunities for students to experience a range of emotions entailed in scientific work, to reflect on these experiences, and to relate their own experiences as doers of science/engineering with those of the scientific community. Materials offer teachers support in bridging students’ engagement as doers of science/engineering with students’ socioemotional development.
3.5. Building Students’ Agency and Authority

In support of a classroom culture in which students see themselves as science learners, they need opportunities to develop agency (the capacity and willingness to engage academically) and authority (having command of the content and being recognized by others as contributors), which will lead to positive identities as science sense-makers, engineering problem solvers and creators of ideas as they contribute to the learning community’s development of scientific ideas and engineering solutions.

3.5.1. Materials will include ample opportunities where students can express ideas that are complex, precise and explicit with everyday language which supports their engagement and sense of being as competent members of a learning community.

3.5.2. Materials will leverage the routines (see Chapter 11) so that students regularly assume responsibility for seamless transitions between learning activities and have opportunities to engage deeply with science and engineering content and processes in ways that promote them asking questions and making comments to foster agency and authority.

3.5.3. Materials support students to take charge of their learning and construct new knowledge by defining tasks, planning, monitoring, changing course of action, and dealing with specific obstacles.

3.5.4. Materials include meaningful opportunities for peers to hold one another accountable for justifying their answers by citing evidence and/or elaborating on their thought processes.

3.5.5. Materials offer teachers strategies to teach students ways to marshal willpower and regulate their attention when encountering complex tasks and unknown concepts.

3.6. Making Science and Engineering Relevant

Teachers and families play critical roles in how elementary children develop. Keeping science and engineering relevant provides an opportunity to have STEM education mean more to all students. To support a classroom culture that is inclusive of all, finding ways to bring everyone’s lives into the experiences is highly valuable.

3.6.1. Materials take into account both teachers and students’ lives outside of school and provide opportunities to bring these interests and lived experiences into the study of science and engineering.
3.6.2. Materials offer teachers structures to bring in non-dominant students’ family and community perspectives, experiences, and expertise into the classroom community to diversify scientific practices and increase the relevancy of lessons.

3.6.3. Materials, especially through carefully crafted and field tested storylines, support family and community engagement to ensure that science class is a culturally-relevant and academically stimulating place for learning.

References


4- Supporting Multilingual Learners

The number of English Learners — children ages 5–17 who speak a language other than English at home continues to rise in the US. In fall 2017, the percentage of public school students who were English Learners was 10% or more in 10 states, including California, Colorado, Florida, Illinois, Nevada, Texas, and Washington. Twenty-one states had percentages of English Learners that were between 6.0 and 10.0 percent, and 14 states had between 3.0 percent and 6.0 percent. More and more English Learners are entering the early grades in elementary school. It is predicted that by 2025, nearly one out of every four public school students will be an English Learner. Spanish was the home language of 74.8 percent of all English Learners. Arabic and Chinese were the next most commonly reported home languages. English was the fourth most common home language, which may also include students who live in multilingual households, or raised speaking another language but currently live in households where English is primarily spoken. To address the diversity of English Learners the term “multilingual learners” (MLs) will be used in the rest of this chapter to acknowledge and value their cultural and linguistic heritages and contributions.

Instructional materials should be designed based on best practices defined in the WIDA English Language Development Standards Framework. In particular, this framework emphasizes the goal of increasing equity for multilingual learners by providing common and visible language expectations in relation to grade-level academic content. This goal is aligned with the intention of these specifications.

4.1. Instructional materials address the language demands by affording multimodal learning opportunities for all students to engage in sensemaking using the Next Generation Science Standards (NGSS) dimensions.

Science instruction for most MLs is still conducted in English thus, students must be provided equitable access to academic content in a language that they are still acquiring. With the implementation of NGSS and the paucity of support to provide exemplary science instruction, there is a need for instructional resources that can enhance experiences and participation for all learners, especially MLs.

4.1.1. Science and language learning are both reciprocal and synergistic. Having meaningful and contextualized activities that address the process of learning science, helps students develop and practice complex language functions.
4.1.2. Instructional materials should leverage students’ language repertoires as an adaptive system of communication that encourages students to use words they know well and words they are learning.

4.2. Instructional materials identify the language functions aligned with NGSS dimensions.

Language functions represent the common patterns of language for a specific purpose. To support MLs in a NGSS classroom, it is important to align language functions with NGSS dimensions and explicitly name the use of the functions in the instructional materials so teachers can support learners in understanding the way language is used in science. As described in the WIDA-ELD standards, there are four key language functions to highlight in elementary science curriculum.

4.2.1. “Narrate” is a function that highlights language to convey experiences through stories and histories. Narratives serve many purposes, and in science the primary purposes include instructing and supporting argumentation. This function should be present, but does not need to be prominent.

4.2.2. “Inform” is a function that highlights the use of language to provide factual information. As students convey information, they define, describe, compare, contrast, organize, categorize, or classify concepts, ideas, or phenomena. In K-2, this function should be most prominent and move to a prominent role in grades 3-5.

4.2.3. “Explain” is a function that highlights the language used to give an account for how things work or why things happen. As students explain, they substantiate the inner workings of natural phenomena and human-made solutions. This function should be most prominent throughout K-5.

4.2.4. “Argue” is a language function that highlights the justification of claims using evidence and reasoning. In science and engineering argue can be used to advance, justify, or defend an idea, claim, or solution. This function should be most prominent in grades 2-5 and prominent in K-2.
4.3. Instructional materials focus on developing a coherence between language functions and science concepts.

4.3.1. Instructional materials focus on how the language functions within the multiple modalities work cohesively to support science content and language specific to the unit.

4.4. Instructional materials enable communication that makes student thinking visible to provide opportunities to strengthen and revise their ideas and explanations.

4.4.1. Instructional materials provide opportunities to make students' thinking visible and the focus of class discussion by collaboratively working in pairs, small groups, or as a whole class to ask questions, clarify claims, discuss questions the teacher or the peers have posed or present ideas relating to the anchoring phenomenon.

4.4.2. Whole class discussions are most beneficial for those activities that the entire class has to perform or understand such as introducing ideas, explaining set ups for labs, expectations, or goals of the unit, and modelling the norms of participating in an academic conversation or discussion.

4.4.3. Working in pairs or small groups allows teachers to understand and gauge students’ needs and give strategic support by modelling or providing scaffolds to adapt to the needs of the collaborative learning activities.

4.4.4. Teacher materials guide the teacher in helping students to adapt their language to meet varying communicative demands.

4.5. Instructional materials support MLs’ engagement and participation in the language functions.

By anchoring science and language learning in multiple modalities instructional materials can provide teachers and students with a reason and a context in which to communicate. Instructional materials should leverage students’ linguistic assets and resources to foster agency and support ML's participation in science classrooms using a range of different interactions.
4.5.1. The instructional materials provide opportunities for sharing the responsibility for learning between teachers and students. Rather than emphasizing “correct” grammar, spelling, and vocabulary, instructional materials focus on students gaining ownership of science ideas by valuing the contribution of ideas given by students of all language proficiency levels.

4.5.2. While MLs engage in language functions, students are supported and encouraged in the use of their everyday language or native language. Students describe their everyday experiences, express their ideas and connect it to the anchoring phenomenon using their home language.

4.5.3. Using their prior knowledge or funds of knowledge, students articulate their experiences from their homes and communities that are used for concept and skill development. Materials support the inclusion of these experiences through the inclusion of culturally responsive and sustaining pedagogical practices.

4.6. Instructional materials sustain science and language development through their supports for teachers.

To encourage teachers to sustain both science content and language acquisition instructional materials provide teachers with contextualized scaffolding so that they can amplify language to support science learning, help students develop metalinguistic awareness, and support their learning over time.

4.6.1. Instructional materials support teachers in encouraging students to strengthen their science learning by focusing on cultural and linguistic contributions that can be used as sources for learning. To deepen science understanding, materials should provide teachers ways to bridge the students’ ideas with science phenomena. Some instances include providing analogies or metaphors and describing teacher moves such as “think aloud” and revoicing. For example, to support ML learners in understanding key ideas about adaptation (LS4.C) such as for any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all, instructional materials might reference analogies such as the difference in houses for people in colder climates that include more insulation and heating systems to aid in survival while in warmer climates.
houses might have more windows for cross-breezes or air conditioning. Students who have migrated from different climates might be able to offer their own examples. Revoicing is where the teachers repeat what the students have contributed either entirely or rephrased using the language functions of the practice. This move gives students a value for their ideas, provides an interpretation of what has been said, and highlights the features of the language function.

4.6.2. The instructional materials provide teachers with support for students to reflect on the use of language and make conscious decisions about how to express themselves in the combined language functions. These supports may take the form of guided prompts or scaffolds for active engagement in a particular function. For example, in constructing explanations, the students engage in describing observations of phenomena and patterns, identifying claims from the data provided, interpreting evidence, and using evidence to support claims. Guided prompts can include “What did you see/observe?” – to elicit how students describe their observations. To elicit how students observe patterns, a prompt such as “What do you notice happening when/if…. (pattern)? Temporary scaffolds can include sentence frames which can be adapted to suit the needs of MLs. For instance, to elicit evidence while constructing explanations, “I observed/analyzed ……” “What I observed is caused by ….”

4.6.3. Instructional materials for MLs reflect a major shift from teaching science terms as a list of words/phrases at the beginning of the unit to integrate the learning of science using the words/phrases within content to enhance understanding. For instance, teachers read text-based explanations, use strategically planned points to highlight words and phrases and prompt student thinking and discussion about the science ideas in the explanation. Teachers also guide students on how parts of text-based explanation are connected using linking words and phrases. Subsequently when students talk and write about text, they can use those words/phrases from the text collaboratively and independently.

4.6.4. Instructional materials include formative assessment to help teachers identify where the students are, where they are going and how to get them to the learning goals in science and language during the process of teaching.
(See Chapter 5 for more on formative assessment.) They provide ways for teachers to continuously explore during the unit how students will access multiple modalities to engage in the language functions as tools for learning. By understanding how MLs are performing in small group settings, teachers can decide on the appropriate scaffolds needed to advance MLs learning. Scaffolds can amplify language, support metalinguistic awareness, and leverage students’ cultural and linguistic resources.

References


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5-Assessment to Inform Teaching and Learning

According to the National Task Force for Assessment Education, “assessment is the process of gathering evidence of student learning to inform education-related decisions. The impact of decisions depends on the quality of the evidence gathered, which in turn, depends on the quality of the assessment, and associated practices, used to gather it.”

Assessment design is considered in tandem with instructional materials design so that the evidence gathered through assessment can inform teachers as they refine their instructional decisions in support of learning. When developing instructional materials it is critical that well-designed assessment opportunities are fully integrated and embedded into the learning experiences. The assessment strategies and tools should support teachers and students in gathering evidence of learning that informs decisions and promotes reflection. These tools and strategies may range from informal assessment conversations that occur during instruction to formative assessment opportunities such as embedded tasks with rubrics that support the interpretation and use of student ideas to inform instruction to summative assessments such as tests, projects, and portfolios. Curriculum-based assessments are not designed to mimic large-scale summative state-level tests, but rather the assessments included with instructional materials support teachers' and students' understanding of what they have learned and how they have made sense of phenomena.

For assessment to inform teaching and learning, there must be not just alignment in the aspects of the standards that are addressed, but coherence between how students learn and how that learning is measured. This means that assessments in OpenSciEd’s materials should be focused on a phenomenon or problem and require students to engage in sensemaking as they demonstrate their knowledge and capacity of the three dimensions of the standards. Further guidance and examples of tasks for grades 3-5 can be found at Task Annotation Project in Science.

5.1. A systems approach is used to design assessments.

Instructional materials use a systems approach to assessment that takes multiple purposes of assessments into account, and ensures that all assessment opportunities coherently provide multiple pieces of evidence that can support claims about what students know and can do in science. The format for the different types of assessments throughout each unit is matched to the assessment purposes. Assessments are sensitive to students' learning
experiences, embedded in instruction, and seen by students as connected to what and how
they learned, and respond to the instructional features of the materials.

5.1.1. Each unit includes a pre-assessment task or discussion to determine what
incoming ideas and experiences students bring to the unit. These formative
tasks are linked to the unit learning goals and phenomenon, design problem,
or driving question. Teacher materials have information for how to elicit
students’ ideas and use them as resources to inform future instruction.
Leveled question strategies may be useful in these activities.

5.1.2. Activities include short, informal, formative assessment opportunities
embedded in ways that teachers can use them to quickly determine whether
students are building understanding. Discourse strategies that encourage
students to share ideas and develop and revise ideas with other students
may be particularly useful for this purpose as they offer teachers
opportunities to listen to multiple students. Teacher materials include
information on how to interpret student ideas to provide feedback and make
instructional decisions.

5.1.3. Formative assessment tasks should be developed with scaffolds across the
year and across grade levels that support students in developing the skills for
sharing their thinking, responding to others’ ideas, and offering useful
feedback.

5.1.4. Instructional materials include key formative embedded assessment tasks to
be used as checkpoints at critical junctures in the unit. Teacher materials
include rubrics on how to provide feedback and make instructional decisions
based on results of these tasks.

5.1.5. Instructional materials include end-of-unit summative assessment (for
every example, a performance task) to determine whether students met the
learning goals for the whole unit that uses a closely related (but separate
from the unit) phenomenon, problem, application, extension, or context.

5.1.6. Instructional materials include student self assessments that are
developmentally appropriate (especially in terms of reading and writing
literacy levels) that teachers can adapt for different units. Self assessments
are opportunities for students to evaluate their learning and growth in the class learning community. Teachers can decide wherever in the unit they would like to help students reflect on their growth. In addition, specific opportunities in the unit are identified where teachers can have their students assess their own progress by using more generic tools that help teachers facilitate this process.

5.1.7. Instructional materials include student peer assessments. Peer assessments involve students giving and receiving feedback from each other and should include non-cognitive aspects of learning. Peer assessments are most useful when there is a range of ideas visible in student work and not all work is the same. Peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. Developers are encouraged to align peer assessment approaches with other common approaches used in elementary school such as Writer's Workshop.

5.2. Assessments measure progress toward three-dimensional learning goals.

Assessment opportunities examine students' performance of scientific and engineering practices in the context of crosscutting concepts and disciplinary core ideas. The multiple assessment opportunities implemented in a unit provide evidence of students' building ability with all three dimensions.

5.2.1. All assessment opportunities ask students to integrate disciplinary core ideas, science and engineering practices, and crosscutting concepts to investigate and make sense of phenomena and solve problems, and occur in multiple modalities and include multimodal representations (such as words, images, diagrams).

5.2.2. Formative assessment tasks ask students to use their incoming ideas, experiences, and cultural ways of knowing to engage with the unit phenomenon or problem, and appropriately scaffold engagement with disciplinary core ideas, science and engineering practices, and crosscutting concepts. Materials for teachers support them to use the evidence from formative assessment tasks to consider how students' background knowledge, cultural ways of knowing, and prior experiences can serve as resources for learning.
5.2.3. Informal assessment opportunities are aligned to three-dimensional learning goals of the particular activity or lesson, based on a bundle of performance expectations, and may scaffold aspects of the three dimensions.

5.2.4. Embedded assessment tasks are aligned to learning goals to that point in the unit, based on a bundle of performance expectations, and may scaffold aspects of the three dimensions.

5.2.5. End-of-unit summative assessment tasks use scenarios involving phenomena and problems, accompanied by one or more prompts, and have multiple components (such as a set of interrelated questions) that yield evidence of three-dimensional learning. Individual prompts and tasks as a whole require students to demonstrate and use each targeted dimension appropriately, use multiple dimensions together, and use three-dimensional performances to sense-make (reason with scientific and engineering evidence, models, and scientific principles). End of unit assessments may incorporate prior grade-level English language arts and mathematics competencies, and use the evidence statements from Achieve and the performance expectation assessment boundaries and clarification statements, as well as the progressions, described in the appendices and prompts in STEM Teaching Tools.

5.3. Assessments are designed to allow for a range of student responses.

Assessment opportunities anticipate the wide range of backgrounds, experiences, literacy levels, first languages, resources, questions, and ideas that students bring to the science classroom. Assessment tasks are dexterous enough to capture students’ background knowledge and initial ideas at the start of the unit as well as how these ideas develop as students integrate information and evidence from activities during the course of the unit. To the extent possible, assessments embedded with instructional materials allow students the option of expressing their emergent understanding in a language and format in which they are most comfortable, and offer students choices in how they respond, for example, orally, in writing, or through a diagram.

Formative assessment opportunities allow for a range of student ideas to be expressed so that the teacher and students can use those ideas to shape subsequent teaching and
learning. Teachers are advised that providing “correct” responses right away undermines the instructional model. Instead, they are guided to provide students with time to make sense of ideas themselves. Formative assessment opportunities allow students from a wide range of backgrounds to participate. Summative assessment opportunities allow for all students to demonstrate where they are in their progression toward the learning goals.

5.3.1. All assessment opportunities are appropriate for diverse populations of students. They have gone through a bias and sensitivity review for all students, including female students, economically disadvantaged students, students from major racial and ethnic groups, students with disabilities, students with limited English language proficiency, and include diverse representations of scientists, engineers, phenomena, and problems to be solved.

5.3.2. Incoming formative assessment tasks incorporate multiple modalities for students’ to share complete, partial, or incomplete ideas, using the process described by the Formative Assessment for Students and Teachers State Collaborative on Assessment and Student Standards (FAST SCASS).

5.3.3. Informal assessment opportunities follow the FAST SCASS process that incorporates multiple modalities for students’ to share complete, partial, or incomplete ideas. They can be discussion-based, and use strategies to allow all students to make their thinking visible (such as providing thinking time to rehearse responses). Informal assessments encourage students to listen to one another, compare and evaluate competing ideas, and merge ideas to construct new explanations. They invite students to revise their ideas based on new information or evidence and include opportunities for teachers to ask follow-up questions or revoice students’ ideas.

5.3.4. Embedded assessment tasks provide opportunities for students to engage with self- and peer-assessment and critique, and provide teachers with actionable information, data, and evidence for planning instructional sequences.

5.3.5. End of unit summative assessments suggest modifications or scaffolding for multilingual learners and special education students and include multiple
task formats (multiple choice, true or false, short answer, and model development).

5.4. Teachers are guided in interpreting and using student ideas.

Assessments, and ways of interpreting those assessments, help teachers understand students' current understanding on a range of less to more sophisticated. Research in the last decade suggests that formative assessment can be a powerful opportunity for elementary teachers to use, integrate, and generate pedagogical content knowledge (PCK). PCK is the knowledge teachers use that blends their knowledge of content with their knowledge of how to teach so that more students learn. As teachers leverage assessment opportunities with PCK, students' opportunities to learn will be enhanced. But developers should be aware that elementary teachers are likely to require additional resources to build knowledge of instructional strategies. Therefore, the instructional materials include assessments and educative materials that support a learning progressions stance, meaning that student ideas are not considered simply right or wrong, but rather as ideas that can be used to support a progression toward higher, or more sophisticated, levels of understanding. Information comes from field-testing directly as a way to capture authentic student experience and learning.

5.4.1. All assessment opportunities provide teachers with examples of student ideas that may emerge and how to use those ideas as resources for instruction. They provide resources for supporting student use of feedback and information to inform their learning.

5.4.2. Formative assessment tasks include possible student responses and strategies for using responses to drive further instruction, for example, Notice and Wondering charts, Driving Question boards, sticky notes, or talk moves.

5.4.3. Informal assessment opportunities include options for talk moves or instructional tasks that help support students on different learning progressions (or with different facets of understanding), including examples of student responses.

5.4.4. Embedded assessment tasks include learning-progression-based or asset-based rubrics and teacher materials that help teachers identify the
range of different student ideas and how to score students using a rubric. They provide guides for peer- and self-assessment that align with the learning progression or rubric.

5.4.5. End-of-unit summative assessments include rubrics for scoring and examples of student responses for each item and rubric level, and provide support to teachers for guiding students toward more sophisticated ideas.

5.5. Because grades are a common part of the schooling experience, even in elementary schools, and districts and schools have varying needs for grading, the instructional materials should not ignore grades or grading, but should emphasize assessment for the sake of learning. Then, in support of the work teachers do, the teacher materials can provide guidance on which student work products are summative in nature and could be graded. Teachers are guided in using student work for grades while also providing meaningful feedback to students so that learning, not grading, is foregrounded. This approach allows educators to choose what to grade based on the needs of their classroom and their district while focusing on student learning and providing meaningful feedback to students about their learning.

5.5.1. Teacher materials provide a summary of grading opportunities that include the intended purpose of the student work and how the work can be used to understand student learning by providing strong student responses and examples of less accurate or less complete student responses, and clear answer keys, rubrics, and scoring guidance that is aligned to those tools. These examples should be guided by data from field testing and research on how typical prior conceptions influence student understanding.

5.5.2. Teacher materials identify assessment opportunities for every lesson and at least one major grading opportunity at the culmination of each unit. By providing regular checkpoints teachers will be able to assess student progress and offer students feedback. Teachers may choose to use these opportunities as grading opportunities depending on their district or school policy.
References


6-Designing Educative Features

The goal of educative instructional materials is to efficiently support teacher learning as well as student learning. Educative features are the elements added to the base materials that are explicitly intended to promote teacher learning. For elementary teachers these features need to support the development of subject matter knowledge, pedagogical content knowledge, the confidence to use teaching strategies that support 3-dimensional learning experiences in which students are “figuring out” phenomena, and the integration of ELA, mathematics, and social studies. In addition, it is critical that the teacher materials are explicit about the rationale for each feature included to support teachers’ decision making about how they will use the instructional materials. OpenSciEd’s educative features are designed to support the wide range of teachers who use the instructional materials and to help teachers find the support they need, when they need it. The educative features should be designed so that the ones a teacher accesses in their first year using the materials are different from those accessed in future years when the material is more familiar.

6.1. Instructional materials support equitable science teaching.

All students deserve to experience rigorous and consequential science learning. By attending to issues of equity explicitly, educative features within science materials work to promote a more just, equitable, and inclusive society.

6.1.1. Lessons incorporate high leverage teaching strategies and best practices to support teachers to meet the needs of diverse learners such as emerging multilingual learners, economically disadvantaged students, students from groups traditionally underrepresented in science, students from non-dominant communities, students with special needs, students who need extra challenge, and other students who may need particular support. These can be customized for specific locations or contexts.

6.1.2. Teachers are guided to adapt lessons as appropriate to incorporate local examples and make other changes that maintain rigor, but increase local relevance (for example, suggestions in instructional sequence or narrative descriptions).

6.1.3. Instructional materials support teachers of emerging multilingual learners, and all teachers, by providing student-friendly definitions, connections to
cognate words, and other language supports that have been documented to support language learners.

6.1.4. Instructional materials support teachers to help prompt cultural connections, including both ideas that can be emphasized as connections as well as what should be avoided. They provide teachers with strategies that help teachers elicit student thinking and recognize students' diverse ideas as resources on which to build (for example, sample student work, suggestions in instructional sequences, rubrics with sample teacher comments, or vignettes of a student story).

6.1.5. Instructional materials support teachers of students with special needs by incorporating the principles of Universal Design for Learning (see guidelines here). In addition, the materials may provide suggestions for potential modifications such as changes to a specific expectation; and accommodations such as provision of additional scaffolding, that could be made (for example, suggestions in instructional sequence, call-out boxes, or videos of enactments).

6.2. Teachers are guided in teaching toward a Next Generation Science Standards (NGSS) vision.

Instructional materials are aligned to the goal of moving classrooms toward the intention and vision of A Framework for K-12 Science Education and the NGSS, with instruction driven by students figuring out phenomena and solutions to problems and aimed toward rigorous and consequential science learning for every student.

6.2.1. Teachers are guided in understanding that each of the three dimensions requires both subject matter knowledge and pedagogical content knowledge.

a. At the unit level, teachers are provided links to resources that support understanding each dimension, which may include links to specific Framework sections or appendices, or to National Science Teachers Association webinars. These resources help teachers understand each science practice, crosscutting concept, and disciplinary core idea (with examples and non-examples), and how practices differ from process skills, why each element is a fundamental element of the NGSS vision, and what the connections are (how practices work together, how
crosscutting concepts thread across disciplines, and how disciplinary core ideas connect to one another).

b. At the lesson level, additional guidance is provided to help teachers recognize specifically where each dimension is at play in the lesson plan, support students in engaging in each relevant practice, see the crosscutting concepts within and across units, develop disciplinary core ideas through engaging in practices, and anticipate the challenges students are likely to face when engaging in each relevant practice or developing an understanding of each relevant crosscutting concept or disciplinary core idea.

c. To support the uptake of science and engineering practices in the elementary classroom, it is important to recognize that teachers may have less background and familiarity with these ideas. Materials can support the use of scientific practices in a manner that helps teachers and students move incrementally toward more ambitious science teaching in elementary classrooms.

d. In particular, the construction of scientific explanations is uncommon and challenging at the elementary level. Educative curriculum materials can support teacher learning in this space by making the value of constructing scientific explanations clear and including specific scaffolds that support students in engaging in explanation construction and argumentation.

6.2.2. Teachers are guided in understanding what constitutes a phenomenon, understanding what phenomenon are developmentally appropriate for the elementary grade bands, recognizing what makes a phenomenon productive for exploration, and making the shift from students learning about ideas to figuring out how phenomena work, including helping them see what this looks like when students do it (for example, graphic organizers, samples of student work, or links to outside readings or videos).

6.2.3. Teachers are guided in developing a set of high-leverage science teaching practices, such as leading a sensemaking discussion, supporting small group work in investigations, eliciting students’ ideas, developing classroom norms for discourse and work in the disciplines of science, and supporting students’ explanation and argumentation (for example, videos of enactments, narrative descriptions of enactments, or links to outside readings or videos).
resources). Instructional materials provide lesson-specific supports including discussion questions, tasks, or problems that a teacher can use to elicit students’ ideas; student roles, discourse norms, and accountability mechanisms for small-group work in investigations; and discourse moves and scaffolds. They provide classroom-level supports, including guidance on developing discussion norms, routines, and protocols for explanation, modeling, and argumentation, and suggestions (such as posters and table cards that include pictures and words) that can support students in developing and implementing classroom norms for discourse and work in the disciplines of science. See this list of high-leverage practices from the University of Michigan or this vision of ambitious science teaching from the University of Washington.

6.2.4. Teachers are guided in their use of assessments. Instructional materials provide supports for engaging in a range of assessment forms, including informal, formative, and end-of-unit summative, including rubrics with sample teacher comments, sample student work, call-out text boxes, as well as support to promote understanding of how each form contributes to students’ science learning, and strategies for addressing the practical challenges of assessing many students in a timely manner.

6.2.5. Instructional materials include guidance for making productive adaptations based on the needs of the class that make instruction more accessible (such as a continuum of scaffolding), paying particular attention to scaffolding students’ early experiences with science practices.

6.2.6. Instructional materials help teachers see how each of the three dimensions build coherently over time within and across units of the program, and provide strategies and visuals for helping students see where they have been and where they are going.

6.3. Instructional materials will recognize that elementary teachers teach more than science and coordination among subject areas and grade levels is essential for coherence and efficiency.
6.3.1. The language of the teacher supports should be situated in teachers' practice and context recognizing the multiple demands placed on elementary teachers and suggesting ways to set priorities.

6.3.2. Provide rationales that help teachers recognize how the recommendations in the instructional materials may differ from their current practices.

6.3.3. Use multiple approaches to highlight important content and connections. Options might include explicit content storylines that are displayed graphically, student-friendly and developmentally appropriate definitions of key ideas, especially science and engineering concepts and disciplinary practices.

6.3.4. Make explicit connections to language arts and mathematics common core standards.

6.4. Instructional materials support teachers and students to spend more time engaged in teaching and learning.

Instructional materials encourage classrooms where effective management supports students in rigorous and consequential learning. Effective management means teachers and students spend less time on non-instructional issues and more time engaging in teaching and learning.

6.4.1. Teacher materials support effective preparation, classroom management (including grouping of students), materials management (obtaining, organizing, distributing, and cleaning up), space organization, and development of productive classroom norms. For each lesson, they provide photos, drawings, or videos of classrooms or artifacts that illustrate effective preparation or management strategies. Teacher materials provide alternatives for teachers with limited storage space, no sink (water or drainage) in the classroom, or other particular needs that differentiate elementary classrooms from secondary classrooms designed for teaching science. (See Chapters 15 and 16 for more details.)
6.4.2. Teacher materials help teachers anticipate likely lesson pitfalls and how they might be able to either prevent or recover from them (for example, via narratives).

6.4.3. Teacher materials provide guidance for the effective and equitable inclusion and use of digital tools for different technology setups (single-computer classroom, one-to-one classrooms, shared computers). See Technology Integration Practices (TIP) Guide for ideas to support teachers with the integration of technology in their teaching.

6.4.4. Teacher materials support teachers in communicating with families and caregivers, administrators, and other stakeholders (for example, by providing sample text for newsletters describing the intent of the OpenSciEd materials, or descriptions of projects or assignments that will require time or resources from home). See Chapter 1 for more ideas related to linking school science to the home environment.

6.4.5. Where appropriate, teacher materials provide suggestions for effective opportunities for getting outside the classroom (for example, the school yard, nearby parks, or field trips to the zoo, aquarium, pond, woods, or museum) as well as options for assignments and activities for such trips and scripts about the value of the trips that teachers can use when seeking funding and approval for field trips.

6.5. Teachers are guided in the use of the instructional materials.

Instructional materials are designed for efficient and effective use, particularly designed so teachers can experience success early on and then dig in deeper to continue learning as they use the materials over time. Educative features help to guide that learning process.

6.5.1. Teacher materials highlight how the embedded UDL principles support all learners and include guidance on how instruction can be differentiated, and include tools and alternative activities that teachers can use selectively depending on individual student needs, classroom needs, school or community contexts, or district priorities.
6.5.2. The front matter of units and program-level materials provides guidance to help teachers recognize and use different aspects of the instructional materials. They present educative features in a user-friendly format, and suggest that teachers may focus on working on one or two elements of their instruction at a time (rather than trying to attend to all of the educative features included in the materials).

6.5.3. Teacher materials inspire teachers and support them in realizing that engaging in this work will have bumps in the road, but that those challenges can be productive for teachers’ own learning and can support future change (for example, via narrative descriptions of enactments, or videos of enactments or interviews with teachers).

6.5.4. The front matter provides guidance for explicit integration of disciplinary literacy and science.

6.5.5. Where appropriate, teacher materials provide recommendations for resources for further exploration (such as readings, videos, simulations, professional development opportunities, graduate coursework), recommend that teachers join professional learning communities or engage in other types of collaboration with colleagues, and help teachers see connections to common pedagogical approaches and common school-based rituals (such as science fairs or exhibition nights) that can be leveraged for and integrated with the intentions of NGSS.

6.5.6. For more complex investigations or design challenges, videos are provided for teachers to help them understand the setup and the materials.

6.5.7. All investigations are designed to meet safety standards for elementary using a set of safety specifications to be approved by OpenSciEd. Examples of acceptable specifications can be found on NSTA's website [NSTA Safety Resources](https://www.nsta.org/safetyresources).

6.6. Instructional materials are effective and efficient.

Instructional materials effectively and efficiently support teacher learning. Every student deserves a teacher who understands and is able to use new instructional materials that
support current reforms. Teacher materials are developed based on research about effective instructional design for supporting teacher learning.

6.6.1. Teacher materials include rationales for the design of lessons and units to give teachers confidence in implementing instructional practices that differ from their prior teaching and learning experiences. They are selective about what to include in teacher materials and how, so the materials do not become too lengthy.

6.6.2. Instructional materials anticipate that teachers will adapt them and make suggestions that can help teachers make productive adaptations, rather than assuming teachers will follow lesson plans exactly.

6.6.3. Teacher materials recognize that teacher learning is a process and provide recommendations for changes to make, or techniques to try over time, to build complexity. Educative features are worded positively (for example, “provide time for students to struggle with ideas”) and acknowledge the variability among teachers and recognize that no teacher will use all of the educative features.

6.6.4. Teacher materials use a range of forms to support teachers’ different needs and avoid using extensive expository text. Some support is not directly grounded in teachers’ practice and can be used sparingly (such as call-out text boxes with definitions or information, links to outside readings, videos, or other resources, and graphic organizers). Other support can be directly connected to and used in teachers’ practice (for example, rubrics with sample teacher comments, sample student work, videos of enactments of specific lesson portions, narrative descriptions of enactments, videos of interviews with teachers, student-friendly definitions, or suggestions within an instructional sequence).

References


7–Asking Questions and Defining Problems

A Framework for K-12 Science Education states about the practice of Asking Questions that “Science begins with a question about a phenomenon and seeks to develop theories that can provide explanatory answers to such questions,” and about the practice of Defining Problems that “Engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved.” Therefore, a basic practice of the scientist is “formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered,” while engineers “ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints” as part of the core engineering practice.

An important assumption in this description is that, if students are the ones participating in these practices, then it should be students’ questions about phenomena or engineering problems that drive their activity—and their learning—forward. It should be their curiosities, interests and prior experiences that motivate their learning through the cycles of investigation, analysis, modeling, and argumentation that come out of this science and engineering practice. Next Generation Science Standards (NGSS)-aligned instructional materials explicitly support the practice of asking the following five types of questions:

a. Wonderment questions draw out the awe and wonder of a phenomenon and highlight areas of puzzlement or weirdness. These questions support students’ curiosity and motivation for learning science and are especially important in establishing the driving phenomenon or articulating an engineering problem.

b. Classroom discourse questions that students ask of each other help support productive disciplinary discussions. These instructional materials draw on Michaels & O’Connor’s Conceptualizing Talk Moves as Tools to support academically productive discourse as a framework for supporting these questions.

c. Investigation questions guide the design of a specific investigation. This also includes questions that support the examination and evaluation of criteria and constraints of engineering design solutions. These are the “empirically answerable” questions emphasized in most existing literature about “Asking Questions.”
d. Procedural or design questions are about measurement or methods. These questions often arise while doing investigations and are often taken for granted, but need to be asked and answered explicitly in order to carry out investigations in science, design a solution during an engineering process, or to evaluate existing data.

e. Epistemic questions are about reasons for pursuing specific questions, what we already know and don’t know, and the design and conceptual steps we need to take next and why. This also includes questions evaluating what criteria and constraints are desirable for a particular engineering design challenge. Though students are not solely responsible for asking these questions early on, instructional materials support students in taking increasing ownership over both asking and answering these kinds of questions.

These types of questions are related and interdependent: wonderment questions evolve gradually, perhaps over the course of several lessons, to investigation questions; epistemic questions mediate the evolution of wonderment questions; procedural and design questions may arise from the investigation process, and new wonderment questions may arise from the results of an experiment. This evolutionary process—a continual cycling of refining and broadening—is only made possible through sophisticated use of classroom discourse questions by both teachers and students.

The following design specifications are organized around three foundational design categories:

- coherence (sequencing activities that simultaneously position students’ questions and questioning practices as driving the learning and ensure that particular bundles of performance expectations will be met),
- pedagogical scaffolds and supports (developing a classroom culture that supports students in asking questions and defining engineering challenges), and
- student scaffolds and supports (providing support for students in asking questions, defining engineering challenges, and increasing their agency over time).

We acknowledge that instructional materials alone cannot accomplish the dynamic, student-centered classroom described here and that ongoing professional learning experiences will be needed to support teachers. For further guidance on implementing these design specifications, refer to NGSS Appendix F.
7.1. Student questions and identification of problems drive instruction.

Central to the vision of *A Framework for K-12 Science Education and the NGSS* is that posing questions and identifying problems is the basis of science and engineering, and that engagement in both should be a primary feature of classroom learning. Student questioning and ideas are the foundation of and driver of science instruction; student problem scoping and understanding of the design challenge are the foundation and driver of the engineering process. In addition, students need to be provided with opportunities to apply their understanding and science and engineering practices to answer their questions and design solutions to identified problems. It is expected that data about students’ questions and ideas gathered during field testing will inform the teacher supports in the materials.

As classroom instruction shifts to become student-centered and consequently student question-focused, the need for a supportive classroom culture in which students are encouraged to ask questions and define problems is essential (see Chapter 3). Within such an environment, different types of questions and problems can be identified and used to develop student understanding of core science concepts to explain real-world phenomena. OpenSciEd instructional materials both follow students’ questions and meet the identified learning goals in coherent ways.

- **7.1.1.** Instructional materials connect students’ everyday knowledge, experiences, ways of knowing, and cultural and linguistic assets to the wonderment of the world and school science and to the need to ask questions and define problems. Materials use phenomena that allow for links between students’ questions, desired science content knowledge, and identified bundles of performance expectations.

- **7.1.2.** Teacher materials are structured to anticipate the questions students will ask about a phenomenon or problem and to connect conceptual and epistemic ideas using students’ questions, specific investigations, and lesson-level learning performances. They create a coherent roadmap from the students’ perspective of a developed sequence of instructional activities.

- **7.1.3.** Activities are included that make explicit the importance of students generating their own questions around scientific phenomenon in science instruction (such as a driving question board), and the identification of the scope of the problems to solve during the engineering process.
7.1.4. Instructional materials emphasize and discuss the many reasons scientists have for asking questions and engineers for identifying and defining problems, the different types of questions, and the purpose of asking these different questions throughout the unit for both science and engineering.

7.1.5. Students are supported to first develop their own individual questions prior to group discussions and whole-class consensus building. Instructional materials provide opportunities and scaffolds for students to ask different types of questions and support their understanding of the differences between them and the specific context for each question. In the engineering process, they provide opportunities and scaffolds for students to identify and define problems.

7.1.6. Instructional materials include strategies to support students in asking questions that direct their learning, and to create opportunities for students to iterate on their design solutions in meaningful ways, on multiple occasions throughout the year.

7.2. Students understand that science and engineering involve unresolved questions or problems, and instructional materials support students in navigating this uncertainty.

OpenSciEd seeks to normalize the idea that science and engineering involve unresolved questions or problems, and that not knowing the answer or solution to a question or problem is productive and drives the learning process. Instructional materials support the goal of creating learning environments that embrace students’ scientific and engineering uncertainty, and willingness to accept not knowing the answer to a question that they are asking or a problem that they are defining. Readiness to accept and embrace uncertainty by both teachers and students is a prerequisite condition for student-centered and open-ended activities. Teacher materials guide teachers in creating learning environments that support and scaffold students in navigating uncertainty in the learning process.

7.2.1. Instructional materials explicitly indicate the multiple ways that students assume more and more responsibility over their own learning (within a lesson, a unit, across a year, and throughout elementary school) around asking questions or defining problems.
7.2.2. Teacher materials provide explicit support for teachers to guide students to assume more and more responsibility around asking questions and defining and scoping problems.

7.2.3. Activities afford multiple opportunities for divergent and convergent thinking and support a diversity of questions across the unit around science phenomena and engineering problems for which we might not know the answers to.

7.2.4. Engineering tasks are designed to support student questioning so that they lead to investigations of the underlying science ideas. Teachers and materials need to support students’ shift in thinking from “will this work” to “why does this work” in order to address the disciplinary core ideas.

7.2.5. Teacher materials cultivate an equitable learning community in the classroom by engaging students in activities that promote trusting and caring relationships and a shared understanding of the cultural diversity and linguistic assets of the students. Promoting social norms that support safe and fair participation help teachers develop a safe and supportive space for students’ uncertainty around science and engineering concepts, and focus on the need to ask and answer questions in order to address the uncertainty across the span of a unit. Considerations and norms for equitable class culture are described in Chapters 2, 3, 6, and 13 of the Design Specifications and should be utilized to create this safe space.

7.2.6. Instructional materials provide scaffolds for students as they develop expertise in framing questions and scoping problems across a lesson, a unit, and a year. Scaffolds address various aspects, such as developing good or productive questions where the answer isn’t yet known or there are multiple answers, as well as the different types of questions (for example, sentence starters, the use of a Notice and Wondering chart or Driving Question board, or peer review processes for student partners).
7.3. Opportunities for productive questioning are provided at key instructional junctions within a lesson or across a unit for all students.

Students are provided opportunities for productive questioning at key instructional junctions within a lesson or across a unit. Instructional materials include multiple opportunities that lead to productive questioning for all students, regardless if it is a science or engineering unit. Both teachers and students understand the importance of asking questions, and how asking questions at key points in learning enables them to understand the phenomenon studied. Especially early on in the scientific or engineering process, teachers may need to expertly draw attention to key conceptual gaps or puzzles in existing models or explanations to focus students’ questioning. As the process continues, students become aware of these gaps by themselves. Teacher materials support this form of instructional expertise.

7.3.1. Units are designed to include key transition points or moments that problematize students' current understanding, in order to motivate additional, or the refinement of, questions to lead to new investigations about the phenomenon or problem.

7.3.2. Instructional materials provide opportunities for students to collect evidence from investigations that helps take steps towards resolving the problem or discrepancy in ideas and answering their questions.

7.3.3. Activities are included that focus on the link between the practice of asking questions to the other science and engineering practices, such as planning and carrying out investigations.

7.3.4. Teacher materials identify what needs to be problematized in order to motivate the learning across the entire unit, and provide sample phenomena that could motivate an important next step by raising new problems or discrepancies that allow students to ask a variety of productive questions (for example, flashlight on paper versus mirror, walking through a mirror-house hallway versus a regular hallway, or shiny metal jewelry versus paper-art jewelry).

7.3.5. Teachers are supported with strategies to capture and organize students' questions, and leverage these questions in future sensemaking activities.
(such as a Notice and Wondering chart, Driving Question board, flowcharts, tables, or concept maps).

7.3.6. Instructional materials provide multiple opportunities for both collective and individual record keeping (notebooks) of what questions all students have and what they want to figure out next, explicitly connected to what has gone on before. They provide scaffolds for students to make connections between models, phenomena, and questions explicit.
Planning and Carrying Out Investigations

Instructional materials for elementary settings need to offer opportunities for student investigations that are developmentally appropriate. That means, for example, that K-2 students are planning simple investigations such as planting seeds in different conditions and 3-5 students are learning to control variables and pool data with their classmates to draw conclusions. By creating these opportunities in elementary school teachers and instructional materials will build a foundation that supports the more sophisticated planning and carrying out of investigations at middle school. All of this foundational work discourages a focus on the 5-step “scientific method” that is an overly simplistic version of doing science based on the rote following of a protocol.

The Next Generation Science Standards (NGSS) promote a version of scientific investigation that is part of a complex constellation of knowledge-building practices. What counts as an “investigation” is broad and emphasizes the need to generate evidence so that students engage with the data. Equally important, a hands-on activity without talk or discussion around planning it, carrying it out, and interpreting and communicating what happened, is not considered an investigation, even if evidence is generated. For further guidance on implementing these design specifications, refer to the NGSS Appendix F.

Investigations honor student agency to support student engagement and learning of disciplinary core ideas, practices, and crosscutting concepts.

Instructional materials provide opportunities around specific investigations to accommodate students’ developing and evolving epistemic agency so that students’ questions can be addressed in meaningful ways. Initially, developing questions to investigate is challenging for students and requires practice so that students can identify and ask questions that can be investigated and answered through the collection and analysis of empirical data. These investigations need to be tied to the local community and cultural assets of the students so that they are authentic, relevant, and have a purpose from a student perspective that can be related back to the original student question and build to the next question.

Teacher materials guide teachers in how to allow students the space to plan and carry out meaningful, theory-based, valid, and reliable investigations while avoiding taking over the responsibility for the process, making the decisions about the process, or ending up scripting the experimental process.
8.1.1. Instructional materials promote meaningful investigations for students by providing opportunities to pursue investigations that stem from their own questions.

8.1.2. Units include multiple investigations so that students practice the planning and carrying out investigations and develop agency in the process. Planning and carrying out investigations is part of every unit with increasing levels of sophistication across the year and across grade levels, so that students are building a foundation and love of science that supports their studies in middle and high school.

8.1.3. Lessons and activities provide multiple opportunities for public documentation of all aspects of an investigation by students, including opportunities for students to identify and make public questions for investigation around a phenomenon, mechanistic models of a phenomenon, or an engineering design solution so they might revise, refine, or propose new questions for investigation.

8.1.4. Instructional materials embrace uncertainty and provide space for investigations that allow for students not knowing an answer or for being uncertain about next steps. They emphasize the importance of learning through productive hurdles and failures, embrace the challenges and uncertainty inherent in scientific investigations, and provide opportunities for students to make decisions and learn from them.

8.1.5. Explicit instructional supports allow for the development of student agency and ownership of learning across the unit using metacognitive strategies (for example, checklists, organizational tools, flow charts, notebooks, Driving Question Board, or model tracker). In addition, careful inclusion of scaffolds for some students (students with disabilities, multilingual students) may need to be considered as a strategy for developing their student agency and ownership of learning.

8.2. Instructional materials highlight connections between the practice of planning and carrying out investigations to the other practices and crosscutting concepts.
Students are supported to apply ideas present in the practice of planning and carrying out investigations in ways that explicitly and seamlessly link to other practices and crosscutting concepts. Planning and carrying out investigations is viewed as an organizing structure (hub) for the other science and engineering practices. The structures and systems for planning and carrying out investigations should systematically support elementary students in developmentally appropriate ways across the grade levels. For example, students should be encouraged to create multiple representations of their thinking, not just written words. In addition, teachers can write and add to anchor charts and descriptions of group investigations to help pre-readers and writers. Instructional materials emphasize connections between the practices and crosscutting concepts in order to leverage the role investigations have in developing deeper understanding of the disciplinary core ideas.

8.2.1. Students connect investigations to other practices and make explicit the connections between planning and carrying out investigations and other practices. For example, students need to plan and carry out investigations in order to test their current model, and they need to analyze and interpret their data from their investigation in order to develop new models and questions.

8.2.2. The instructional design emphasizes the iterative nature of investigations and connections to other practices, and units provide opportunities for students to engage in a series of investigations in which an answer to the initial question sparks the next question, which requires further investigation. The source of these initial questions might be the instructional materials, the teacher, or the students. Over time a mix of sources of initial questions will provide elementary students and teachers with a range of ways to carry out investigations.

8.2.3. Instructional materials connect investigations to the crosscutting concepts, provide opportunities for students to design investigations, and focus on the connections between designing investigations and the crosscutting concepts (such as patterns, cause and effect, and scale, proportion, and quantity).
8.3. Investigations have an authentic and explicit purpose for student sensemaking.

Instructional materials support students in designing and carrying out investigations that allow students to develop a deeper understanding of the science being investigated. An important component of any investigation is for teachers and the instructional materials to provide time and structures for students to connect the question, evidence, and conclusions of an investigation to their lived experiences and to make sense of the experience.

8.3.1. Investigations are part of an intentional and coherent sequence of activities that may have different roles such as learning a scientific concept, developing an experimental skill, or gaining an understanding of how scientific knowledge is produced. Instructional materials emphasize that the nature of investigations will vary based on the question being asked and the discipline being studied.

8.3.2. Instructional materials focus on investigation authenticity and include investigations that are connected to students’ past experiences in and out of the classroom, especially the community and cultural histories and assets that will inform and motivate students’ own questions.

8.3.3. Classroom science is explicitly linked to the scientific enterprise. Lessons make explicit the relation between the investigations students are doing in class and the scientific endeavor, allowing for explicit connections to the nature of science.

8.3.4. Students apply investigated ideas to the real world. Instructional materials create opportunities for students to apply the investigations they are doing in class to their own lived experiences or meaningful contexts.

8.4. Teachers are guided in creating a supportive space for student-centered investigations by explicit support in the curriculum to understand the role of students’ communities and the cultural assets the students bring to the classroom.

Instructional materials support both students and teachers in learning how to navigate learning with student-centered investigations. Central to this design specification is the idea that all investigations should be designed to include talk and discussions as students are
planning, carrying out, and interpreting and communicating what happened in their investigation.

Planning an authentic investigation involves making a series of decisions that require experience and expertise. These decisions involve identifying and revising questions with a specific purpose in mind as well as understanding how to structure and carry out valid, reliable empirical investigations. Students often struggle with understanding that experiments are based on theory, and that they need to be planned and grounded in selecting specific variables to test, and they must have a reason to conduct the experiment. Students need both teacher and peer support as they engage in science learning by participating in the practices of science, constructing their own understanding of what it means to be a scientist or engineer, and to do and learn from science.

8.4.1. Lessons and activities provide pedagogical scaffolds and supports for helping students plan, conduct, and reflect on their investigations to consider if their work is valid and reliable (for example, providing supports for questioning if their data set was collected systematically or if they have enough data to make a claim).

8.4.2. Instructional materials emphasize the importance of discussions as a core criterion of an investigation and provide support and space for students to talk that is developmentally appropriate while engaging in the planning and carrying out investigations practice. They support rich class discussions for procedural and practical purposes and engage students in discourse to uncover the necessity for gathering observations or data (students are supported in figuring out “what do we need to know?”) as well as to engage students in defining the strategies or methods used for collecting observations or data (“how will we come to get the information we need?”).

8.4.3. Instructional materials support rich class discussions for sensemaking and emphasize the centrality of discourse for sensemaking throughout the planning of and carrying out an investigation (not just at the start and end of the investigation). They emphasize the importance of learning through productive hurdles and failures, embrace the challenges and uncertainty inherent in scientific investigations, and provide opportunities for students to make decisions and learn from them.
9–Developing and Using Models, Constructing Explanations, and Designing Solutions

The practice of developing and using models is a central way that people use science ideas to describe, explain, and predict phenomena in the natural world. Scientists construct both mental and conceptual models of natural phenomena, which support the work of making sense of natural phenomena as well as communicating and revising scientific ideas. This is true for early science learners as well as expert learners of science (professional scientists). Across the elementary grades, students engaged in this practice build from developing and using models as literal depictions of the world towards increasingly symbolic representations of their ideas. Engagement in this practice at the K-2 and 3-5 levels supports students in developing the understanding that our ideas about the natural world can be represented in ways that can be collaboratively visualized, shared, compared, and refined. In addition to developing students’ scientific literacy, engagement in these practices also lays the groundwork for students’ increasingly sophisticated use of this practice in the middle and upper grades.

Developing and using models is an intellectual endeavor that guides scientific sensemaking and communication. Rich engagement in this practice extends well beyond simply drawing pictures. The earliest development of this practice begins with understanding that models can be used to represent concrete materials or events in the natural world. However, it can be challenging to create the conditions in the classroom that engage students in a deeper version of this practice that goes beyond depiction. OpenSciEd instructional materials position models as intellectual tools that students use to reason with and use to develop explanations for phenomena. This intellectual work happens through negotiation between students, whether in small groups or in a whole-group setting, and important learning happens in the discussions students have while deciding how to construct or revise models and how to explain a phenomenon or design a solution. For further guidance on implementing these design specifications, refer to Next Generation Science Standards (NGSS) Appendix F.

9.1. Developing models and constructing explanations are central to the units.

The practices of “Developing and Using Models” and “Constructing Explanations and Designing Solutions” are central to doing science and reflect ways that scientists of all ages make sense of and communicate ideas about the natural world. The creation of models and explanations is both the goal of an OpenSciEd classroom and the means by which learning occurs. Through these practices, students achieve and demonstrate key
understanding of the disciplinary core ideas and crosscutting concepts. Modeling and explanations are also central in that they coordinate and guide the use of the other practices.

9.1.1. The development and/or revision of models, explanations, and engineering solutions is the central activity of all instructional materials. Each unit has one or more models (or model revisions) that serve as organizing features for the unit. Some repeated routines are established within units and across grade levels so students can practice and improve upon development and/or revision of models, and approximately 25% of activities, including home learning connections focus on the cycle of model development or design iteration, explanation or problem solution, and/or revision.

9.1.2. Science and engineering practices are coordinated and support one another. Instructional materials connect modeling and constructing explanations or solutions to the other scientific practices used in the classroom so that they are informed by and inform questioning, investigations, data analysis, math and computational reasoning, argumentation, and communication.

9.1.3. The target disciplinary core ideas and crosscutting concepts of each unit are closely aligned with the development of models, explanations, and solutions. Engaging in these practices is always in service of developing understanding of important disciplinary core ideas and crosscutting concepts. Developing models, explanations, and design solutions are not additional activities but rather are positioned as central to the unfolding sensemaking work of the classroom.

9.2. Supports and scaffolds manage the complex practices of modeling and explanation.

Developing models, explanations, and solutions is complex and cognitively demanding. This process needs to be carefully scaffolded so that students and teachers have the support they require for managing the complexity and demand, while responsibility for the models and explanations remains with the classroom community. Young learners developing this practice often begin by attempting to create literal depictions of the world. Students need support in understanding models as their current conceptual understanding of a system which can be diversely represented, shared, compared, and refined. Early learners may initially grapple to understand that our models represent different ideas.
about events or solutions in the world, and that our different models can be compared for similarities and differences (K-2). From these understandings, students build further capacities to revise, evaluate, and collaboratively develop models, as well as consider how models might have limitations and be designed for different purposes (3-5). It can be initially challenging for teachers and students alike to move beyond depiction and drawings in the modeling practice, or to position models as more than a container for declarative knowledge (a glorified worksheet) to be memorized. Explanations need to go beyond unstructured storytelling. They need to provide clear answers, based on evidence and established model ideas, to how and why questions about phenomena.

9.2.1. The practice of developing and using models always has the purpose of constructing an explanation for a phenomenon or providing the basis for a design solution. An activity to focus the classroom knowledge building work on a specific phenomenon or class of phenomena occurs in the first lesson set of each unit and in other lessons where new phenomena are introduced to drive the model building. Usually the purpose is communicated with a clear question that the model can be used to answer in the form of an explanation or a design solution. In 3-5, these questions begin to drive towards cause-and-effect relationships that move from simple what explanations to why or how explanations. Instructional materials require students to develop explanations using their models, which often requires pressing for an unseen cause of the phenomenon (for example, molecular motion or differential survival).

9.2.2. Instructional materials draw a clear distinction between developing a model and representing it. They avoid the phrase “draw a model” and instead use language such as “develop a model and represent it” that puts the cognitive demand on the students. For example, instructional materials will ask “What do you think needs to be represented in your model?” or “What do you think needs to be revised in your representation of your model?” as opposed to “Today we learned about evaporation. Please be sure it is represented in your model.” The learning occurs as students negotiate what does and does not get included in their models.

9.2.3. Students are provided with explicit opportunities to share their ideas with one another and compare and/or evaluate them based on established criteria. Instructional materials include repeated and explicit conversations
about how to compare and/or evaluate knowledge products in the classroom, and how they connect to other practices. These criteria are established in each classroom at the beginning of the year and revisited in each unit.

9.2.4. Students represent models in multiple ways that convey different aspects of underlying model ideas. Instructional materials require that models about the same ideas be represented in multiple ways to convey underlying model ideas. Typically this is a combination of labeled drawings and text or oral statements. As students move from representing concrete events and design solutions in K-2 towards increasingly abstract phenomena in the middle grades, some models cannot be easily represented in pictorial form (such as natural selection). In those cases it is okay for a model to exist as a list of principles in text only. Models are not represented with drawings or pictures alone. When using simulations, instructional materials ask students to connect the computer output to the underlying rules or code that runs the simulation.

9.3. Modeling and explanation involve comparisons of models and/or an iterative process of revision.

To provide an authentic experience of making sense of phenomena through modeling and explanation, students have opportunities to collaborate around comparing models and begin to engage in the iterative process of revision. Students in K-2 have multiple opportunities to represent and compare simple models of concrete objects, events, and solutions, laying the groundwork for more sophisticated collaborative engagement with identifying limitations, testing relationships, and revising models in grades 3-5. By grades 3-5, students have multiple explicit opportunities to return to their ideas to revise, discard, add, or expand them as they gain new evidence from investigations and other sources (readings, simulations, further observations). Students use their models to develop explanations and in doing so begin to realize where there are gaps or issues that need to be taken up to move forward.

9.3.1. Students develop and revise models and explanations over time based on new information gained through investigations and discussions. By the 3-5 grade band, instructional materials regularly include multiple opportunities to create models, construct explanations, and design solutions, and return to
them to revise them based on their ongoing work. The instructional materials have clear stopping points for this revision to happen and include opportunities for students to develop and share initial ideas about the anchoring phenomena, identify gaps in their understanding, revise their ideas each time they have new information (from investigations, readings, simulations), and return to their models in explicit ways at the end of the unit as they come to closure in explaining the driving questions.

9.3.2. Students have opportunities to connect to and/or apply their models to explain multiple phenomena. Model and explanation or solution development is centered on an anchoring phenomenon. At least once in all units there is an explicit conversation or activity that requires students to consider how their model relates to and/or could be modified to account for a different related phenomenon or be generalized to account for a class of phenomena.

9.3.3. Instructional materials provide explicit opportunities for the students to map between their model and explanations or design solutions. Students use their models when constructing explanations or identify gaps in their explanations that imply a need for new ideas in the model. Going back and forth between explanations and solutions and models is an important feature of these practices. The model identifies key components and relationships among the components, and relates these to the specifics of the phenomenon or engineering design problem. Instructional materials are explicit about these connections toward the middle and end of a unit, and might include a prompt that asks students to write an explanation or develop a solution and then go back to their model and annotate where each part of the model shows up in their explanation or design solution.

9.3.4. Instructional materials require students to use their models for a purpose. Models are dynamic and need to be applied to be useful. When assessing understanding of the models under development, students are asked to use the model to describe components, relationships, patterns, events and/or predictions about a phenomenon, or to describe how the model connects to related phenomena. Most often this involves students using their model to develop an explanation. Students are not asked to simply repeat back an element of a model or even an entire model as an inert fact.
9.4. Students experience modeling, explanation, and problem solving as collaborative processes.

In scientific learning communities (both in classrooms and among professional scientists), modeling and explanation are collaborative endeavors that advance the understanding of the members of the community. Instructional materials are structured so that the work of the classroom community is made public, and students have opportunities to share, compare, critique, and/or build on one another’s ideas throughout each unit.

9.4.1. Activities are structured so that students work together through a collaborative process to develop, compare, and/or revise shared models that represent a class consensus. Instructional materials provide scaffolds and routines that support collaboration and class consensus about models, explanations, gaps that need filling, potential investigations, and/or revisions to the models.

9.4.2. Teacher materials guide teachers in keeping public records of the ongoing models that the students are creating (either digitally or through posting on a wall or board) and provide guidance on the format of those artifacts and how to hold students accountable for keeping their own individual records.
10–Analyzing and Interpreting Data and Using Mathematical and Computational Thinking

Instructional materials provide students with opportunities to learn the practices of “Analyzing and interpreting data” and “Using mathematics and computational thinking,” with ample opportunities for students to use these practices to develop explanations and design solutions. Often when exploring a natural event or thinking about solutions to a problem, we are not just interested in describing what is happening. We are also interested in how much, how fast, or how frequently something has happened, and how it may happen in the future or in a different circumstance. Both of these practices offer specialized ways for describing the observations made during investigations precisely and systematically. At the elementary level working with data also helps students gain an appreciation that recording data helps them keep track of phenomena and ideas over time and also helps others know a little about what they were thinking. In grades K-2, analyzing and interpreting data is about recording and sharing observations and using those observations to describe patterns and relationships in the natural world. In grades 3-5, students develop representations of data in multiple ways to reveal patterns and they develop, explore, and conduct analyses on observations that have been recorded with varying degrees of precision so they can develop an appreciation for precision. These learning experiences should help students think about how instruments vary but can still provide information even when there is wide variation in measurements. Using mathematics is about determining when and how to describe a system of interest quantitatively while computational thinking focuses on using tools and/or simulations to analyze and visualize data sets, mathematical relationships, or solutions to engineering tasks. For further guidance on implementing these design specifications, refer to NGSS Appendix F.

10.1. Instructional materials focus on students’ ability to contextualize data, mathematical models, and simulations.

Data, mathematical models, and simulations are human-constructed abstractions of the world. Data are conceptualized as collections of numerical values (lengths, number of occurrences, weights, intervals of time, amounts) or qualitative representations (field notes, sketches, maps, photos, video or audio records) collected from systematic observations of the natural world, investigations such as experiments, or generated through automated means such as simulations or environmental sensors. In elementary school, students work with data by learning to record information (such as observations, drawings, counts, and measurements), using simple graphs, tables, or other forms of representation to display
data and look for patterns, and, in upper elementary school, comparing and contrasting data collected from different groups. Mathematical models describe the important quantitative patterns and relationships embedded in natural systems. In elementary school, students focus on determining when and how to use quantitative information (such as counts and basic measures), how to represent quantitative information using simple graphs, and how to describe objects using estimates and quantities. Simulations are computer models that encode some of the behaviors or relationships that unfold in scientific systems over time. In elementary school, students may engage with simulations, such as animation software, to model the rules of simple phenomena, like phase changes. A perpetual challenge for students is to connect these abstractions back to the world from which they originated.

Elementary students come to school with working knowledge of the natural world based on their time outside in the neighborhood, viewing media, or family travels. These experiences can be used as a resource for thinking about how data, mathematical models, and simulations are created. At the same time, the conventions used to create these abstractions (for example, the processes of obtaining and recording data, describing quantitative relationships, or translating behaviors in the world into computer algorithms using age appropriate methods, like block languages such as Scratch™ or Blockly™) are tacit and are supported through well-facilitated instruction. Supports will help teachers uncover and build on students' prior understandings and create opportunities to see the rationale that underlies existing conventions. The goal is to help students recognize that data, mathematical models, and simulations are created and used by humans to make sense of and explain the natural world.

10.1.1. In kindergarten, an introductory unit should introduce students to the concepts of measurement and data collection by engaging students in a shared investigation that emphasizes the importance of recording data and remembering what that data represents. Subsequent units and grade levels should build in sophistication to introduce students to concepts of measurement and data collection aligned with the expectations outlined in the Common Core State Standards for Mathematics (for example, using the standards outlined in the “Measurement & Data” domain in grades K-5).

10.1.2. Materials acknowledge where scaffolding needs to be provided to support the use of developmentally appropriate mathematical and data analysis skills in the disciplinary context (for example, by looking for patterns in data to
determine that as one variable increases, so does another). Materials also
gauge reasonable boundaries and identify necessary scaffolding for the skills
needed to engage in data analysis in elementary school and beyond.

10.1.3. In units that involve collecting and working with data, students reflect
explicitly on measurement. When collecting data themselves, students are
given opportunities to choose between multiple measurement and recording
options, or to develop their own. When provided with data, students are
asked to consider how measurements and observations were made and
discuss possible alternatives. In at least one unit per year, students have the
opportunity to collect data using a variety of measurement and/or
observational methods they select themselves, compare the results of their
findings, and then iterate on their data collection methods.

10.1.4. In units that involve working with data, mathematical models, or simulations,
students are asked to describe connections between what is visualized or
represented and their real-world referents. Instructional materials include
opportunities for students to consider what important features of the
phenomenon under investigation might be missing from the dataset,
mathematical model, or simulation.

10.1.5. Units in grades K-2 provide students with opportunities to compare data
representations from two different possible solutions to a problem. By
grades 3-5, unit activities provide opportunities for students to observe and
reason about multiple outcomes (for example, by comparing data from
different conditions in an investigation of plant growth), which is especially
appropriate for engaging students in the testing and comparison of
proposed solutions to engineering design problems.

10.1.6. Units provide students with opportunities to create their own mappings
between abstractions and natural phenomena, for example, by supporting
students to choose how to draw, count, or observe a feature of interest and
to consider how different ways can do different kinds of work.

10.1.7. To avoid treating data analysis, mathematical models, or simulations as
input-output processes that simply generate results rather than as models of
the world, instructional materials focus on grounding both the inputs and
outputs of these sources of data. Units that involve data, mathematical models, or simulations include opportunities for students to explore mappings between abstracted input parameters (individual data points, input variables, simulation setup conditions) and the natural phenomenon of interest. Units provide students with opportunities to make predictions about what real-world outcomes will result based on a given set of inputs before an output is calculated.

10.1.8. Students have opportunities over the course of a year to record their own observations of natural phenomena, with the goal of recording those observations as data, mathematical models, or simulations. For example, students may be asked to determine the parameters worthy of measurement for a planned investigation, like selecting whether to measure weight, ramp height, friction, or all three when investigating factors that influence how an object moves down an inclined plane. Students may also be asked to hypothesize potential patterns in collected data or to observe a system (like changes in shadows over the course of a day, the moon cycle, or projectile motion) with the ultimate goal of describing its behavior in terms of mathematical functions. For example, students might characterize biodiversity in their community using data collected about local species and calculations of rectangular area.

10.2. Students develop their statistical, mathematical, and computational toolkits.

Once students have assembled or been provided with a data set or simulation and understand its connection to the natural world, they can begin to make use of tools to explore the patterns within. The practices of “Analyzing and interpreting data” and “Using mathematics and computational thinking” both involve selecting and making use of a wide variety of technological, conceptual, and representational tools. Some are broadly useful, such as bar graphs, dot plots, line graphs, and data tables. Others, such as maps or timelines are more specialized and may only be appropriate in certain circumstances. Creating opportunities for students to understand and navigate this landscape of available tools is critical for engaging in the practices of data analysis and mathematical and computational thinking.

Tools are often used to collect and analyze data about the natural world. Students should be introduced to a variety of simple tools and foundational approaches for working with
data (such as tables and graphs). They should also be given opportunities to learn about how to use these tools and when they might be useful. A challenge for students is to recognize that on one hand, there is no “one right way” to analyze or model natural phenomena (in fact, sometimes using multiple tools together provides more insight into a data set or system). On the other hand, certain tools are more appropriate to use depending on the investigation you are conducting or the problem you are solving, and some tools may be inappropriate or lead to invalid conclusions. It is in this space that precision and variability could be emphasized - measuring with a meter stick vs a shorter ruler that has to be moved or measuring with homemade instruments vs more professionally produced ones. One powerful way to address this challenge of understanding there is not necessarily “one right way” to collect data is to leverage the diversity of approaches that students are likely to bring to any classroom investigation. Different student approaches to the same investigation might be more or less useful in moving students’ investigations forward, and different tools might be useful in different ways. This approach avoids the implication that there is one right way to conduct analysis or modeling, but it does teach that some approaches can be inappropriate for a particular task. Through repeated experiences making use of these tools, especially to address well-grounded problems whose connections to natural phenomena are known, students can begin to appreciate when and why certain tools work for some investigational contexts, but not others.

10.2.1. In grades K-2, students are introduced to foundational mathematical, graphical, and digital tools for working with data and continue to learn about these tools with increasing sophistication into grades 3-5. Students are provided with opportunities to practice setting up and using these tools to collect, organize, and analyze data in the context of an investigation where students attempt to answer a scientific question or solve an engineering problem. Students are also provided with opportunities to talk about the benefits and limitations of various types of tools.

10.2.2. Students are given many opportunities—especially toward the beginning of the academic year—to choose, apply, share, and compare among a variety of mathematical, graphical, and digital tools while working on a shared problem or investigation.
   a. As part of these opportunities, students review and critique their peers’ solutions, are asked to consider how different approaches
might highlight or hide important features of the phenomenon under study, and are given the opportunity to modify their own approaches.

b. Starting in grade 1, at least one opportunity each year focuses on creating representations (for example, line plots, pictographs, bar graphs, etc.) to identify relationships among variables of interest in an investigation.

c. Students of in all grade levels should have opportunities to compare or see the same data in different representations that align with the types of representations they have learned to create or are used to seeing as data displays.

d. In grades 3-5, at least one opportunity focuses on selecting from a variety of graphical displays (maps, charts, graphs, tables) or displays that students invent themselves to analyze data. At least one opportunity focuses on selecting from a variety of digital tools when analyzing data (spreadsheets, data visualization tools such as Tuva, TinkerPlots, or CODAP), working with mathematical models (graphing tools such as Desmos™), or creating or interacting with simulations (Scratch™, Blockly™, NetLogo).

10.2.3. Students are asked to explore the nature and causes of variability in data, and to discuss whether it exists naturally or because of measurement error. Variation from both error and natural variation is acknowledged in every unit involving data sets collected from the natural world. Students have opportunities to recognize human error and natural variation in data. Students have an opportunity to observe or discuss the degree to which natural variability is accounted for (or more often, not accounted for) in mathematical models and simulations of scientific phenomena.

10.2.4. Whenever they analyze data collected from the natural world or produced by simulations, students are asked to consider questions of causation, correlation, and significance.

a. In any unit that requires students to make conclusions based on differences between measures in collected, provided, or simulated data, students’ intuitions about statistical significance (as reflected in differences between measures or trends) are elicited and reconciled with their intuitions about practical significance (dependent on the situation and circumstances).
b. In any unit that requires students to make conclusions based on relationships or trends identified in data, differences between causation and correlation are raised and considered. Students are asked to share whether or not they believe that any other explanations are possible to describe correlational results. They are introduced to controlled experiments as one method to explore causal relationships.

10.3. Data, mathematics, and computing are specialized forms of modeling.

The prior issues focus on emphasizing the human-constructed and interpretive nature of work with data, mathematical models, and simulations. Because of their complex and technical nature, students might continue to see these abstractions as illustrations of factual truth, rather than models constructed by humans to highlight particular aspects of a scientific phenomenon. Alternatively, they may view them merely as communicative artifacts meant to show their own knowledge of scientific facts, rather than also as a way to figure out the world.

To address this challenge, instructional materials position all data sets, mathematical models, and simulations—regardless of whether they are provided as a part of instructional materials, sourced by students during investigations, or created by students—as scientific resources and models whose validity is established through their connections to natural phenomena, explanatory and predictive power, and utility toward particular student-defined goals. Students construct and make use of more sophisticated mathematical or computational models to explore, explain, and predict complex causal chains or multi-level relationships in systems.

10.3.1. Data visualizations, mathematical expressions or equations, and simulations are put forth as options for students to use to represent models. Mathematical expressions are appropriate for encouraging students to clearly articulate and elaborate models that predict certain quantitative relationships. They are a useful way to plan and prepare for controlled experiments. Simulations are an appropriate way for students to express and test their models of enacted behaviors in a wide variety of scientific systems (physical, chemical, or ecological). Introducing data, and encouraging students to develop data models, is an effective way to provoke critique and revision of their earlier models.
10.3.2. When multiple examples are available, students are invited to compare data, mathematical models, or simulations pertaining to the phenomenon under study to explore what each emphasizes or downplays.

10.3.3. Data, mathematical models, or simulations are never used as a direct check of student work or theories. Instead, they should be presented as an additional resource and evaluated based on criteria established by the classroom community.

10.3.4. In any unit that makes use of curriculum-provided data sets, mathematical models, or simulations, students are asked to consider their “life cycle.” Specifically, students learn about and question who authored the data sets, models, or simulations, what their goals were, what they chose to select and leave out, what are the possible limitations and threats to validity imposed by this resource given students’ own interests and paths of investigation, and whether students would have made different decisions if they were the authors instead. Supports are provided for teachers to facilitate this discussion in their classrooms (such as example question prompts, educative materials about the nature of data, various data representations, and common data practices used in specific disciplines).

10.4. Instructional materials sustain data analysis, mathematics, and computational thinking as classroom practices.

For students to develop more complex understandings of interpreting and analyzing data and using computational thinking, instructional materials must shift from a focus on learning concepts to a focus on co-developing concepts alongside these practices. Practices are a form of hidden instruction, and inviting students to contribute to the development of practices can help them understand their overarching purpose, when and why they are useful for developing knowledge, and how to participate in and transform those practices in service of their own personal, in-the-moment goals. For example, one common goal in elementary school is for students to become proficient with creating and using graphs. Students develop these skills by developing, interpreting, and referring to graphs as they explain phenomenon or to justify a solution to a problem. For students, the move to practices means learning new things (practices as well as concepts), doing so in new ways (invention, critique, and revisiting), and playing a central role in determining what counts as
good work (students, rather than teachers, evaluating their own work and the work of others).

For teachers, the move to practices means developing a classroom culture that supports both qualitative and quantitative exploration of empirical information; engineering student encounters with problems of practice; orchestrating cycles of construction, critique, and revisiting; and supporting the interplay of individual and collective histories of development. Instructional materials encourage students to connect their use of data, mathematics, and computing across different problems and experiences. The idea that practices make use of a broad, flexible kit of mathematical and computational tools rather than "how-to scripts" is reinforced by careful scaffolding and sequencing as students learn these practices then revisiting, maintaining flexibility, and building connections across the tools and approaches students use during various investigations over time.

10.4.1. Teacher materials emphasize and provide examples of ways to build a classroom culture that supports exploration and student sensemaking while working with qualitative and quantitative information. This includes:
   a. Providing guidance and examples of how to establish norms for talking about data, models, and simulations that emphasize rationale and justification over correct and incorrect answers
   b. Providing activities, tools, and rationale to uncover students’ intuitive understandings and funds of knowledge about how to work with data from their everyday and home experiences (for example, students’ ideas about measurement and precision in relation to observed cooking practices, sports, etc.)
   c. Examples of ways that teachers can support students with developing positive relationships and views toward quantity, computation, and mathematics.
   d. Offering guidance for helping students consider the original context that the data are about and that those data were a record someone had to make from that context.

10.4.2. Teacher materials characterize the intended development of data, mathematical, and computational concepts and practices in construct maps or learning progressions. These maps provide teachers with interpretive systems they can use to evaluate a range of student products, describe a continuum between expected beginning and ending points in a given unit or
grade to address the progressive nature of learning, and offer guides to help teachers understand the range of student responses expected during a given activity, and decide on next steps in instruction.

10.4.3. Instructional materials support the development of practices with sequenced experiences. A unit might begin with measurement and contextualization tasks, move to encoding, invention, and comparison tasks, offer new contexts in which preferred tools and approaches might be re-employed or expanded, provide ways to connect preferred tools and approaches to one another, and make use of recurring classroom activity structures (for example, familiar cycles of invention, critique, and revisiting practices in formative assessments with new content or tools).
11–Arguing from Evidence and Obtaining, Evaluating, and Communicating Information

Students learn more when engaged in meaningful forms of argumentation and communication. Argumentation engages students in opportunities to construct and defend their claims using evidence, as well as critique arguments presented by others. For this to happen at least two conditions are critical: a classroom culture that supports argumentation and communication and instructional materials that provide structured opportunities for students to participate in arguing and communicating about elements of their work for the authentic purpose of explaining a phenomenon or designing a solution, at increasing levels of sophistication over time. In particular, the classroom culture and supporting materials need to promote the shared goal of consensus, achieved through collective norms practices that promote scientific argumentation. It is important to note that the CCSS-ELA does not use the term “argument” for the elementary grades. Rather these standards make a connection to science by saying that “students make claims in the form of statements or conclusions that answer questions or address problems. Using data in a scientifically acceptable form, students marshal evidence and draw on their understanding of scientific concepts to argue in support of their claims. Although young children are not able to produce fully developed logical arguments, they develop a variety of methods to extend and elaborate their work by providing examples, offering reasons for their assertions, and explaining cause and effect. These kinds of expository structures are steps on the road to argument. In grades K–5, the term “opinion” is used to refer to this developing form of argument.” For further guidance on implementing these design specifications, refer to Next Generation Science Standards (NGSS) Appendix F and The Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects: Appendix A.

11.1. Argumentation and communication vary across individuals, classrooms, disciplines, and out-of-school contexts.

Enabling every student to be successful requires creating opportunities for students' home experiences, and ways of knowing, to be a productive part of the classroom sensemaking. Instructional materials support this by illustrating the ways argumentation and communication vary across individuals, classrooms, disciplines, and out-of-school contexts. They include vignettes, sample student work, interviews conducted with scientists and engineers about their argumentation and communication, and comparisons of the language used to describe these practices. For further guidance, refer to NGSS Appendix F.
11.1.1. The instructional materials need to support both teachers and students in the creation of a classroom culture that supports scientific argumentation and communication. (See Chapter 3 for more ideas on classroom culture.)

a. Introductory unit that establishes, negotiates, and routinizes classroom culture and norms that supports argumentation.

b. Key lessons in which argumentation is foregrounded should be organized by a shared goal of consensus as a means of making sense of evidence.

c. Science activities should be framed as opportunities for collective sense making.

d. Language directed to students should emphasize epistemic agency and accountability for claims in developmentally appropriate ways. (Consider whether the Science Writing Heuristic (Hand et al. 2005), which promotes student voice and scientific reasoning is useful.)

e. Strategically consider when students work individually, in small groups, or participate in whole class discussions.

f. Include material resources that are useful for producing knowledge claims such as charts, graphs, tables, diagrams, and drawings of data and evidence. These resources can be based on extant data or data gathered by the students.

g. Include writing probes that support students to 1) explain how they know, what they know, and why they know, 2) justify arguments with evidence and reasoning, and 3) think about alternative viewpoints and evaluate them.

11.1.2. Teacher materials include educative features that emphasize instructional strategies that support student argumentation and communication. (See Chapter 6 for more background on educative features.)

a. Support a shift in teacher questioning from factual recall to more divergent questioning patterns allowing for increased student voice. This critical role for the teacher promotes argument by shifting the questioning pattern to produce more active student voice; as student voice increases, elements of science argumentation are practiced.

b. Include open-ended questions to launch investigations, probing questions to press for elaboration and justification, and later questions that help students build consensus based on the quality of the evidence available.
c. Provide time and structures for students to construct explanations in which they make claims based on sound evidence, present those claims to peers who either accept or refute them, discuss multiple views, and reach classroom consensus.

d. Strategically consider when students work individually, in small groups, or participate in whole class discussions.

11.1.3. Teacher materials include educative examples for teachers to help them understand the productivity inherent within student variation of ideas and practices (for example, synthesized vignettes of classroom activities, sample student work, or transcripts or videos of classroom activities).

a. Examples show variation in how individuals participate (participation does not always require verbal participation in whole-class discussions) and ways that students argue and communicate successfully (emphasizing differences that stem from students’ backgrounds and experiences, familiarity with the practices, comfort with English).

b. Teacher materials provide examples of how teachers explicitly use and build on students’ ideas, including incomplete or inaccurate ideas that do not initially appear productive. They show how teachers explicitly make connections among student resources, what students are doing in science classrooms, and the intended disciplinary practices associated with argumentation and communication.

c. Examples show variation in the sophistication of the students’ scientific reasoning and articulation of their thinking, and in school contexts and student demographics (gender, race, language proficiency) to highlight the ways that all students are capable of engaging in argumentation, and obtaining, evaluating, and communicating information.

d. Examples of students engaged in arguing and communicating in the sciences and engineering enable teachers to help students see how communicating and arguing are interrelated but different. Examples show variation with respect to when in the investigation students are arguing and communicating so that it’s clear that these practices aren’t only part of a culminating task.
11.1.4. Educative examples show teachers the ways in which the variation shown in
the examples is consistent (or inconsistent) with disciplinary practices (for
example, how scientists and engineers argue and communicate and why).

11.1.5. Examples show how to emphasize the productivity of what students are
doing, and help teachers think about ways they can recognize and build on
student resources for engaging in argumentation and communication,
including multimedia examples and vignettes (such as real classroom videos
and audio clips).

11.2. Students participate in argumentation and communication at increasing levels of
sophistication and decreasing levels of scaffolding over time.

Instructional materials support students in participating in argumentation and
communication practices in increasingly sophisticated ways as they become increasingly
familiar with these practices. Sophistication includes the structure, content, and
interactions within the students’ communication and argumentation, as well as the context
(scaffolding and activity structures).

11.2.1. Instructional materials use the Common Core State Standards for English
Language Arts to support and scaffold grade-appropriate uses of the literacy
skills in their transfer to grade-appropriate science practices. They
acknowledge where scaffolding needs to be provided in order to support a
more sophisticated use of literacy skills in the disciplinary context, and to
gauge reasonable boundaries and identify necessary scaffolding for the
literacy skills needed to engage in scientific argumentation and
communication in high school and beyond.

11.2.2. The claim-evidence-reasoning framework is used to support students in
argumentation, particularly in the earlier grades. The use of this framework
fades over time, and teacher materials provide both general and specific
prompts at different points in the unit. Instructional materials support
students in distinguishing between fact and inference (or even speculation)
and provide opportunities for students to develop a clear understanding of
what constitutes a claim and the types of evidence (data and observations
gathered systematically) and reasoning (logical versus emotional) that are
valued in science.
11.2.3. Students have multiple opportunities within a single unit and across the instructional materials to practice evaluating the credibility, validity, and reliability of the information they obtain, and to practice communicating information to a variety of audiences for different purposes (for example, a scientific audience for the purpose of sharing research, their families for the purpose of sharing what they are investigating in school, a local museum for the purpose of helping to construct an exhibit). Students practice selecting the genre of communication that best suits a given audience and purpose, and they have opportunities to move across multiple representations of the same ideas.

11.2.4. Lessons and activities provide students with a purpose for argumentation and communication. Students can do more when they are engaged in meaningful forms of the practices—when they have an authentic reason to argue or to communicate in various ways—thus scaffolds are imbued with a purpose that aligns with the expectations such that student work can be meaningful. Scaffolds do not oversimplify such that they obscure the sensemaking purposes.

11.2.5. Instructional materials provide students with opportunities to identify and obtain information from a variety of sources and depending on purpose (for example, interviews, print text like journal and review articles and newspapers, videos, photographs, graphical representations). Students learn to search and use databases and various search engines to obtain information.

11.2.6. Teacher materials include educative supports that help teachers model their thought processes when evaluating whether information is accurate, credible, or useful.

11.2.7. Students are provided examples of how to evaluate information in light of the task at hand. For example, some data may be interesting and credible but useless given the task. Students start to use a scientific stance of “skepticism” to evaluate the information based on the quality of evidence and reasoning, or any potential bias that might come from the author’s intended purpose and audience.
11.2.8. Instructional materials support students in creating arguments and communicating ideas that increase in content sophistication but also in the sophistication of the contexts in which the argumentation and communication is happening, recognizing that teacher led discussions are often a less sophisticated form of the argumentation and communication than student to student discussions because of the teacher's dominate role.

11.3. Students engage in argumentation and communication to explain phenomena or design solutions to problems.

When students are engaged in meaningful forms of argumentation and communication—when they have an authentic reason to argue or to communicate—their learning is more effective. Instructional materials ensure that students are arguing and communicating about elements of their investigative or design-related work (involving the other practices), for the authentic purpose of explaining a phenomenon (or elements of it), or designing a solution.

11.3.1. Instructional materials create contexts in which students are explicitly focused on figuring something out, developing explanations or solutions, and on the criteria they use to evaluate their ideas and processes, rather than focusing solely on demonstrating acquisition of a “right” answer.

a. The goal of argumentation and communication is sensemaking—figuring it out—by using particular scientific or design criteria as they attend to that goal. The accurate answers, or evidence rich explanations, are a tools to achieve the goal, rather than being a goal in and of itself. Instructional materials make these criteria part of the assessment and discussions.

b. With respect to engineering, the criteria are project “constraints and criteria” that become the primary means of evaluation (and can offer the potential for multiple “right” answers, as long as the design requirements are achieved).

c. With respect to argumentation and communication, teachers and students are asked to explicitly build on evidence, past experiences, or shared ideas to address the question asked, construct ideas with appropriate levels of generality, and address the needs of their audience.
Lessons ask students to self-assess their own arguments, designs, and communicative practices and products, in addition to assessing those of others. For example, What worked well in my design? What parts of my argument were well supported? What parts might require more evidence or better explanation? Given my audience, did the communicative genre I chose help them understand my ideas?

11.3.2. Lessons and activities make students’ work with argumentation and communication public because argumentation and communication are inherently public practices (whether written, spoken, or illustrated). Making an argument public, for example, is essential for others to respond and evaluate the thinking and reasoning behind it. This means both sharing final form ideas and showing, discussing, and debating works in progress, including justifications for students’ decisions.

11.3.3. Units provide students with opportunities to engage in purposeful revision of their argument and communication-related processes and products. For example, students revise their solutions, claims, explanations, or arguments if they receive feedback that it does not address elements of users’ needs, does not align with the investigative question, or does not attend to the evidence generated. Students re-examine their choices if they select a genre that is not aligned with the intended audience and purpose (such as writing the discussion section of a scientific poster as a story rather than an argument when writing for a scientific audience).

11.3.4. The practice of argumentation happens where uncertainty is expected and enabled, either as a result of disagreement or because they are in the midst of sensemaking.
   a. Argumentation can also occur around questions that feel resolved to students. Students must have a meaningful reason for engaging in argumentation in these situations. For example, they might be providing an argument others could use, or articulating their final form argument in a way that could convince others.
   b. Argumentation occurs throughout science investigations, not only as a culmination of students’ work. Students may argue about the appropriateness of their questions, research methods, or data interpretations, just like scientists do.
c. Argumentation occurs throughout an engineering design project, not only as a culmination of students' work. Students may argue about their interpretations of the user's needs, about which materials, resources, and methods they think will work best in the design, about how well a design fits the criteria, and about the relative prioritization of different potentially competing design criteria as well as other considerations such as feasibility of construction and optimization.

d. Argumentation does not always require consensus. Teacher materials help teachers identify when consensus is necessary and when it is not. Argumentation occurs in speaking (talk stems, teacher and peer modeling) as well as writing (sentence stems, graphic organizers, and opportunity for revision).

11.3.5. In instructional materials, students obtain, evaluate, and communicate information throughout an investigation or design project, not only as a culmination of students' work. For example, students obtain and evaluate background information that helps situate their investigative work, or they might conduct user needs assessment.

   a. Students communicate their preliminary investigative findings, or the affordances and constraints of their designs, to other peer groups, in addition to communicating findings, understandings, explanations, or design solutions, to teachers, community groups, or family members. Students consider audience, purpose, and genre when engaging in science and engineering-related communication, and they experience many opportunities to communicate to different audiences, for different purposes, using a variety of genres, in speaking as well as writing.

   b. Students use information from a variety of sources (books, journals, online blogs, videos, photographs, interviews with community members) and decide what information and sources are most relevant to their tasks as part of their investigative work. In some instances, students learn how to search for these sources (conduct keyword searches in online databases, learn to use their libraries' systems for finding sources and information, learning how to conduct information-gathering interviews with family and community members), while in other instances activities include texts in varied
formats and genres that provide evidence and other information needed for sensemaking.

c. Instructional materials include excerpts or adapted versions of important science formats, including the opportunity for students to make sense of diagrams, tables, graphs, and procedural instructions. Texts do not provide an explanatory account of the phenomenon, but rather are a source of evidence, a component piece of information that can contribute to figuring out the phenomenon, or additional examples and counterexamples to allow students to support claims or reject claims, or to generalize claims or narrow claims as needed.

d. In order to develop both receptive (reading and listening) and productive (speaking and writing) communication skills throughout the investigative and design processes, supports are provided for listening in addition to reading, such as the setting of norms and expectations for active listening, teacher talk that sets the expectation for listening to and working with the ideas of peers, talk stems, and teacher or peer modeling.

11.3.6. Engineering design projects use disciplinary core ideas in authentic and purposeful ways such that those ideas are clearly necessary for achieving the design goals. Instructional materials might also expose students to real examples of how scientists and engineers use the practices of arguing and communicating as part of their work. Students explore why and how this is essential to the field and to building knowledge and a collective understanding about our world. Instructional materials embed some vignettes or real-world examples of a way someone's engagement in argumentation and communication has helped respond to a question or propose solutions to a problem related to the core ideas being explored in that unit.

11.4. Students participate in argumentation and communication at increasing levels of sophistication and decreasing levels of scaffolding over time.

Instructional materials support students in participating in argumentation and communication practices in increasingly sophisticated ways as they become increasingly familiar with these practices. Sophistication includes the structure, content, and
interactions within the students’ communication and argumentation, as well as the context (scaffolding and activity structures).

11.4.1. Instructional materials use the Common Core State Standards for English Language Arts to support and scaffold grade-appropriate uses of the literacy skills in their transfer to grade-appropriate science practices. They acknowledge where scaffolding needs to be provided in order to support a more sophisticated use of literacy skills in the disciplinary context, and to gauge reasonable boundaries and identify necessary scaffolding for the literacy skills needed to engage in scientific argumentation and communication in high school and beyond.

11.4.2. The claim-evidence-reasoning framework is used to support students in argumentation, particularly in the earlier grades. The use of this framework fades over time, and teacher materials provide both general and specific prompts at different points in the unit. Instructional materials support students in distinguishing between fact and inference (or even speculation) and provide opportunities for students to develop a clear understanding of what constitutes a claim and the types of evidence (data and observations gathered systematically) and reasoning (logical versus emotional) that are valued in science.

11.4.3. Students have multiple opportunities within a single unit and across the instructional materials to practice evaluating the credibility, validity, and reliability of the information they obtain, and to practice communicating information to a variety of audiences for different purposes (for example, a scientific audience for the purpose of sharing research, their families for the purpose of sharing what they are investigating in school, a local museum for the purpose of helping to construct an exhibit). Students practice selecting the genre of communication that best suits a given audience and purpose, and they have opportunities to move across multiple representations of the same ideas.

11.4.4. Lessons and activities provide students with a purpose for argumentation and communication. Students can do more when they are engaged in meaningful forms of the practices—when they have an authentic reason to argue or to communicate in various ways—thus scaffolds are imbued with a
purpose that aligns with the expectations such that student work can be meaningful. Scaffolds do not oversimplify such that they obscure the sensemaking purposes.

11.4.5. Instructional materials provide students with opportunities to identify and obtain information from a variety of sources and depending on purpose (for example, interviews, print text like journal and review articles and newspapers, videos, photographs, graphical representations). Students learn to search and use databases and various search engines to obtain information.

11.4.6. Teacher materials include educative supports that help teachers model their thought processes when evaluating whether information is accurate, credible, or useful.

11.4.7. Students are provided examples of how to evaluate information in light of the task at hand. For example, some data may be interesting and credible but useless given the task. Students start to use a scientific stance of “skepticism” to evaluate the information based on the quality of evidence and reasoning, or any potential bias that might come from the author's intended purpose and audience.

11.4.8. Instructional materials support students in creating arguments and communicating ideas that increase in content sophistication but also in the sophistication of the contexts in which the argumentation and communication is happening, recognizing that teacher led discussions are often a less sophisticated form of the argumentation and communication than student to student discussions because of the teacher's dominate role. To enable every student to successfully participate in scientific practices, instructional materials attend to the linguistic demands inherent to engaging in the particular practices of arguing and communicating across productive (writing and speaking) and receptive (reading and listening) language functions.
11.5. Instructional materials support the linguistic demands of arguing and communicating.

11.5.1. Instructional materials provide a variety of examples of language supports for teachers that can help their students with linguistic demands (relative to writing, speaking, reading, and listening).

a. For argumentative and communication-related writing and speaking, the instructional materials make use of supports like sentence starters and talk strategies.

b. Instructional materials make use of listening strategies, such as helping students learn to pay attention to words that are repeated often, and stressed words (that are spoken longer and louder) because these words are usually an indication of importance. With respect to supporting students in listening to each other, instructional materials emphasize the importance of talk strategies for listening carefully, using phrases such as, “I hear you saying that...,” “If I understand you correctly, your claim is...,” and “I think you are saying that your audience is....” Additionally, the materials provide supports for helping students learn how to productively summarize or add to what their peers are saying (for example, teachers are prompted to ask, “Does anyone want to add onto that?” and “Can anyone summarize what they said?”).

c. For argumentation-related writing, speaking, reading, and listening, instructional materials make use of supports like vocabulary instruction of argument-related words, peer modeling, and the modeling of language expectations for an activity.

11.5.2. Instructional materials encourage teachers to reflect upon how their students currently engage in the language requirements embedded in arguing and communicating, and reflect on their own instructional strategies for supporting students in this literacy work.

a. Teachers are guided in using strategies to better understand what students think argumentation is and how students go about arguing in various contexts in their lives. For example, teachers can ask students to pick some activities in which they engage outside of school and identify what they might argue about in those activities, what claims they might have to make, what types of evidence they use...
to support their claims, and how that is dependent on the activity itself (for example, in basketball there might be an argument about whether someone traveled, and video tape might be analyzed to find evidence to support that someone did travel). From there, teachers can compare the structures and processes involved in students’ everyday argumentation with the structures and processes involved in scientific argumentation.

b. Teachers are guided in using formative assessments to better understand what students know and are able to do with respect to obtaining, evaluating, and communicating information (Do students know how to use search engines and keyword searches to obtain information? Do they know how to assess the credibility of a source that they find? Do they know how to select an appropriate genre to communicate their explanations given the intended audience?).

c. Instructional materials support teachers and students in the use of techniques like functional grammar analysis to identify certain patterns in scientific texts (such as compare and contrast, problem and solution, or cause and effect).

11.5.3. Instructional materials use language supports like discourse markers to analyze existing arguments and to produce them. They support teachers in helping students learn to identify discourse markers in scientific text and talk, and use them in their writing and speaking. For example, markers can include words and phrases such as “because,” “we contend,” “therefore,” and “others might argue.”

11.5.4. Teachers are guided in using these different language supports at various points throughout the materials, ideally when students are about to engage in a particularly demanding task. Teacher materials include suggested language supports when appropriate, including when a task is introduced for the first time (for example, the first time students read their peers’ written arguments to give them feedback related to strength and persuasiveness). However, a language support is not included for every lesson. The goal is for teachers to build a repertoire of practices that they could incorporate to better support their particular students.
11.5.5. Instructional materials embed metacognitive prompts to support teachers with having metacognitive conversations around the disciplinary literacy goals associated with argumentation and communication.

a. For argumentation, teachers and students are prompted to ask the following types of questions: What is the claim being advanced? What is the evidence for this claim? Is the evidence convincing? Is all of the evidence being considered? Are all of the plausible claims being addressed? Is the reasoning logical and valid? Why or why not?

b. For obtaining, evaluating, and communicating information, teachers and students are prompted to ask the following types of questions: Given the phenomenon we are exploring, what types of information do we need to obtain to better understand that phenomenon? Where should we look for that information? How will we know if the information we find is credible and accurate? What are the important ideas that need to be included in the explanation? What would be the best way to organize the ideas? How did we decide the best way to organize the ideas? What is the purpose for this communication and who is the intended audience? What format would best be used to communicate with this audience for this purpose? Is my choice of language suited to the audience?
Crosscutting concepts are central to robust and applicable science understanding. Crosscutting concepts are not mere key terms, facts, or definitions for students to learn. Rather, they are ways of understanding and organizing scientific questions, ideas, and practices and engineering problems and challenges as they relate to real-world phenomena. Crosscutting concepts are rich, recurrent lenses that support students to bridge their funds of knowledge and current science learning, scaffold scientifically productive questioning and sensemaking about natural phenomena, provide creative linkages to consider an engineering problem, and facilitate conceptual connections across various phenomena, science domains, and other disciplines. At the elementary level, the explicit development and use of these crosscutting concepts provides the foundation for their increasingly intentional and sophisticated use as familiar tools for sensemaking and problem-solving about natural phenomena as well as offering opportunities to leverage connections to student learning in ELA and Math.

Crosscutting concepts are not taught in isolation, but continually developed in conjunction with disciplinary core ideas and science and engineering practices as students explore, explain, and make sense of phenomena at increasing levels of sophistication within units, across units, and across grades. As with DCIs and SEPs, the learning goals in a unit should target specific grade-level elements of the crosscutting concepts that have been selected as focal (or foregrounded) for development and/or use within the unit. Other crosscutting concepts that are peripherally relevant but not centered for development and/or used during students’ sensemaking may be backgrounded for some or all of the unit. For further information, including sample prompts and responses for each of the crosscutting concepts to support instruction and the development of formative and summative assessment performance tasks, refer to Using Crosscutting Concepts to Promote Student Responses developed by the CCSSO Science SCASS Committee on Classroom Assessment.

Crosscutting concepts are continuously integrated with the other two dimensions in ways that students recognize are relevant and useful to the context of the unit.

To support the teaching and learning of three-dimensional science understanding, instructional materials maintain the interconnectedness of the crosscutting concepts with the disciplinary core ideas and science and engineering practices consistently through the units. The crosscutting concepts are not additional content or information that students need to learn separately but are used as a way of thinking about and understanding the disciplinary core ideas and science and engineering practices in relation to the phenomena
under study. Crosscutting concepts can provide *epistemic heuristics* that guide student thinking towards productive reasoning about scientific phenomena. Crosscutting concepts can be leveraged to: identify productive questions and goals for investigation; support analogical reasoning; provide rules for scientific sensemaking; and identify essential evidence to figure out a mechanistic explanation for phenomenon. For examples of these characteristics in use, see Anderson, Gane, Hmelo-Silver, Mohan, and Vo (2018).

12.1.1. Instructional materials intentionally integrate instruction of the crosscutting concepts with instruction on disciplinary core ideas, science and engineering practices, and phenomena.

   a. Storylines for units and lessons make students aware of the crosscutting concepts they are learning about and using to address the anchor phenomena, in the same manner and to the same degree that they make students aware of the disciplinary core ideas and science and engineering practices they are learning.

   b. Lessons are designed such that the teacher and students use the language of one or more crosscutting concepts each time they discuss how a disciplinary core idea relates to a phenomenon (as part of classroom dialogue, writing prompts, peer feedback, or assessments). At minimum, students are asked to reason with at least one grade-level element of a crosscutting concept in each set of lessons.

   c. When appropriate, lessons or tasks are designed to feature how the crosscutting helps students see the connection between a disciplinary core idea and the phenomenon or to connect different disciplinary core ideas or phenomena together. Language such as “related to” or “applied to” is used often for structuring classroom discussions, writing prompts, modeling activities, and assessment tasks. One type of formative or summative assessment task that may be used in each unit is to ask students to engage in a practice (model, explain, argue, analyze, question) to express the relationship between a disciplinary core idea and a phenomenon in two or three different ways using different crosscutting concepts (for example, first with patterns, then with cause and effect, then with energy and matter).
12.1.2. Instructional materials avoid common pitfalls with integrating crosscutting concepts as part of three-dimensional learning.
   a. All lesson sets include a reference, discussion, or activity involving at least one grade-level element of a crosscutting concept. While a crosscutting concept is not the focus of each lesson, instructional materials prompt both teachers and students to think about and apply the crosscutting concepts to phenomena and disciplinary core ideas.
   b. Crosscutting concepts are part of the storyline that students are figuring out as they work through the unit. Instructional materials do not ask or direct students to think about any of the crosscutting concepts without some explicit attention, instruction, or scaffolding that makes the development and/or use of the crosscutting concept(s) salient from the student perspective. This support is present yet sensitive to where the activity is situated with respect to prior instruction and is flexibly responsive to student learning needs. Sources of support include educative features, supplemental resources, and instructional moves integrated into the lesson.
   c. Units do not include a “mini-lesson” or a stand-alone section on each crosscutting concept. Instead, they introduce and reinforce the development of a grade-level element of a crosscutting concept in the context of the problem or scenario students are working on.

12.2. Students experience an increase in the sophistication and complexity of their understanding of all crosscutting concepts across units and courses in an identifiable and planned manner. For example, units are designed to provide students multiple, sequenced opportunities to develop and use grade level elements of crosscutting concepts that build on one another across a course. Development of crosscutting concept elements are paced to enable students to build capacity with all of the grade level elements of the crosscutting concepts by the end of the grade band.

Students’ three-dimensional understanding of science is developed in ways that increase in sophistication and complexity across units and grades with an intentional and visible plan. The introduction and development of each of the seven crosscutting concepts across units and grades reflects this overall commitment. Each crosscutting concept is distinct with its own learning trajectory across the elementary grades. Instructional materials help teachers
and students see and understand these learning trajectories and provide visible and intentional opportunities for students to reflect on and demonstrate changes in their learning of each crosscutting concept across units.

12.2.1. The sophistication and complexity of crosscutting concept understanding increases across units and grades based on the element-level descriptions of the crosscutting concept learning progressions provided in the Next Generation Science Standards (NGSS) Appendix G, especially the transitions between grade bands. Teacher materials map the learning trajectory for each crosscutting concept across units and courses in ways appropriate to the context and conceptual focus of the units. When appropriate, the design of activities and lessons include supports for teachers and students to recall and build from previous crosscutting concept understandings developed in prior units. Teacher materials provide unit-level support that identifies what current student understanding of and experience with crosscutting concepts is assumed, and suggested adaptations or scaffolds for addressing situations where students may not have the assumed prior learning experiences. Instructional materials include both formative and summative assessment opportunities for students to demonstrate and document their current understanding of each crosscutting concept over the course of a unit and across units within a year.

12.2.2. Instructional materials avoid common pitfalls with developing crosscutting concept learning trajectories over time. They do not teach a crosscutting concept only once in the elementary grades, but rather provide multiple opportunities for students to engage with each of the seven crosscutting concepts across units in each course. They also do not teach each crosscutting concept the same way each time, varying the structure, routine, or template to each use of a crosscutting concept, and making use of the element-level descriptors of the crosscutting concept to guide these decisions. While teachers and students are supported in using consistent language in discussion and writings about crosscutting concepts, how students are asked to think about, reason with, and apply crosscutting concepts in three-dimensional learning varies across units and courses in ways that challenge students.
12.3. Students engage in multiple crosscutting concepts in each unit, and students reason with and discuss all seven of the crosscutting concepts over the course of the grade band (K-2 and 3-5).

In three-dimensional science learning, there is not just one way to relate a disciplinary core idea to a phenomenon through a practice. There are multiple ways to relate disciplinary core ideas to phenomena, and crosscutting concepts are a set of tools and resources that teachers and students use to do this. Every science concept has one (or more) of the crosscutting concepts that constitute what it means to understand that idea. Facts that can be known without crosscutting concepts are not three-dimensional and are not the focus of instruction. Explicitly using multiple crosscutting concepts to relate disciplinary core ideas to a phenomenon (through student questions, explanations and/or models) makes the crosscutting concepts a powerful dimension for students and can make the robustness of their scientific reasoning and understanding visible to both teachers and peers.

12.3.1. Students build towards engaging with multiple crosscutting concepts in each unit. Activities and lessons guide teachers and students to reason about the anchoring phenomena in different ways. When possible, there are at least two opportunities in a unit for students to think about the anchoring phenomenon and other phenomena in ways that are similar to how scientists would draw on different perspectives to wonder about or explain the same thing. Each of these perspectives should use a different crosscutting concept to reason about the phenomenon. As student learning progresses across units, materials are designed so that students take more responsibility and ownership for considering phenomena using different crosscutting concept perspectives. In early units, activities are clearly specified and closely scaffolded to provide students with support for thinking from multiple perspectives. Later units provide less structured tasks and more open opportunities for students to engage in this kind of relational sensemaking around constructing explanations or solving problems around phenomena, both individually and socially in groups or as a whole class.

12.3.2. Instructional materials avoid common pitfalls with engaging students with multiple crosscutting concepts around phenomena. They avoid aligning a single crosscutting concept to a disciplinary core idea or anchoring phenomena. While a lesson set might focus more explicitly on developing an element from one foregrounded crosscutting concept, there are opportunities
in the unit for students to consider other crosscutting concept perspectives on that same idea or phenomenon. Activities do not ask students to apply a crosscutting concept without some form of responsive instructional supports or scaffolding.

12.4. Students use consistent language of crosscutting concepts in all units, particularly when discussing phenomena and engaging in science practices.

Crosscutting concepts are not seven distinctly different, unrelated ideas. Together, they are a set of resources to support scientific reasoning and meaning making. Crosscutting concepts are also central to communicating science (between peers or between student and teacher, verbally or written). To help students understand the role that all of the crosscutting concepts play in supporting reasoning and meaning-making, instructional materials use common language when discussing crosscutting concepts.

12.4.1. Instructional materials use consistent language about crosscutting concepts within and across activities, lessons, and units to support students’ developing understanding and application of crosscutting concepts.
   a. When students discuss phenomena, they use the language of crosscutting concepts as a lens or a way of “looking at” or “seeing what’s going on.” For example, materials can provide supports, models, or scaffolds for students to talk about seeing a system or recognizing a pattern in a phenomenon or experiment.
   b. When students are establishing and articulating relationships between disciplinary core ideas and phenomena or to other disciplinary core ideas, they use the language of the crosscutting concepts as a bridge or connector to make the relationship visible and salient. For example, instructional materials support students to write initial explanations for an unexpected event by connecting the observed causes and effects to science ideas they learned about before.
   c. When students are engaging in science practices, they use the language of the crosscutting concepts as tools to encourage engagement in more meaningful ways. Materials use features of the crosscutting concepts as prompts to structure classroom dialogue or written responses as students engage in the different practices. Asking students to be clear about how the crosscutting concepts are
used in the science and engineering practices builds these concepts into powerful tools and provides common language for students to discuss and share ideas when collaborating in the practices.

d. When the class is figuring out how to organize concepts or relate seemingly disparate phenomena to each other, students use the language of crosscutting concepts as rules to help students organize and categorize their understanding. This is a way to make the big ideas visible for students that can often get lost when focused on individual examples of phenomena. Students and teachers can use the language of crosscutting concepts as rules toward the end of a unit or set of investigations to place new insights and understandings in the context of the broader disciplinary core ideas that are developed across units and courses.

12.5. Students have opportunities to leverage crosscutting concepts to access their funds of knowledge as resources for sensemaking and to make connections between their learning in classroom communities to communities beyond school.

Crosscutting concepts are intended to provide a framework for student development of a coherent scientific worldview that can be used to make sense of and connect student experiences. The utility of this framework extends beyond student experiences in a single science course to include phenomena encountered both within and outside of schools. These crosscutting concepts can be leveraged to support students in bridging their prior knowledge, interests, and experiences as resources for scientific sensemaking about particular phenomena within their current science classroom community. Moreover, the development and use of crosscutting concepts can provide opportunities for students to connect and transfer their sensemaking about phenomena within one science classroom to their learning in other classroom communities or their communities beyond school. Beyond supporting deeper student thinking about particular aspects of the target phenomenon under investigation, these expansive uses of crosscutting concepts can support students' sense of agency and identity as science learners.

12.5.1. Instructional materials provide opportunities for students to use crosscutting concepts to identify and organize their own ideas, interests, and experiences as potential resources for asking questions and figuring out natural phenomena or solving problems.
12.5.2. Instructional materials provide opportunities for students to use crosscutting concepts to surface and share connections between their sensemaking about phenomena within their science classroom to phenomena they observe in communities beyond the classroom. For example, this may include student connections to students home or cultural communities or to broader socio-scientific issues they have encountered.

Reference

13–Classroom Routines

Creating equitable learning opportunities depends critically on helping students connect the science and engineering they are learning to their own ideas, reasoning, practices, and experiences. As noted in Chapter 2, in a culturally relevant and sustaining classroom, student voices are welcomed and encouraged. It is important to note that BIPOC students’ contributions in class are often considered off topic or disruptive when they do not contribute in manners typical of the dominant culture. Classroom routines are activity structures designed to engage all students in inclusive and welcoming routines repeatedly over the course of a year and across multiple years to serve several goals. Structured routines with discrete steps that have explicit goals can serve as scaffolds for students to learn sophisticated scientific or engineering practices. They can help teachers develop and use strategies for centering students’ own questions. They can support the establishment and maintenance of a classroom culture by providing norms and expectations about behavior and social interaction. Routines contribute to efficient use of time because once students have learned a routine, they can begin the work with minimal direction and focus their attention on the work of the routine rather than how to do the work.
In extant OpenSciEd instructional materials for middle and high school, there are five established routines as illustrated above. Developers are expected to use these routines in a foundational manner for elementary materials to support a trajectory of learning for students K-12 as described in Chapter 1 of the Design Specifications.

13.1. The Anchoring Phenomenon Routine: Kicking off a Unit with an Experience to Motivate Investigation

The Anchoring Phenomenon routine is used to kick off a unit of study and drive student motivation throughout the unit. The purpose of the Anchoring Phenomenon routine is to build a shared mission for a learning community to motivate students in figuring out phenomena or solving design problems. More specifically, the Anchoring Phenomenon routine serves to ground student learning in a common experience and then use that experience to elicit and feed student curiosity, which will drive learning throughout the unit. The Anchoring Phenomenon routine also serves as a critical place to draw out students’ prior knowledge and relevant experiences to help connect the questions students raise or problems they identify with their prior knowledge and lives outside the classroom. The Anchoring Phenomenon is introduced at the beginning of a unit.

13.1.1. Units provide multiple opportunities for public representations of student questions. At the opening of a unit, and as students make progress on models and designs, lessons provide opportunities for students to raise questions about phenomena or to inform design solutions. A Notice and Wondering chart or Driving Question board are just two examples of tools that create a public repository for students’ questions created within the first few lessons and updated throughout the unit. All units use comparable routines to compile and track questions about phenomena and designs. Lessons include supports for teachers to work with students to connect to the questions students have generated to motivate the work and to monitor progress.

13.1.2. Instructional materials support students in generating questions by eliciting students’ current understanding about phenomena and problems and asking them to make sense of the phenomena, generate ideas about how to solve a problem, and connect the phenomena or problem to their own experiences.
13.2. Navigation Routine: Motivating the Next Step in an Investigation

The Navigation routine helps connect the science and engineering students are doing with the questions and problems their class has identified. The routine is central in enabling students to experience the unit as a coherent storyline in which each activity has a purpose and is connected to what has gone before and what is coming. It also provides a valuable opportunity for students to reflect on their learning over time. The Navigation routine is conducted throughout the unit at transition points, such as between lessons.

13.2.1. Student questions are key to the navigation and coherence from the students' perspective because they provide a clear purpose that links one activity to another. Throughout the units, lessons prompt teachers to bring students back at regular intervals to the record of questions to determine which ones have been addressed, which haven't, and to determine if there are new questions or problems.

13.2.2. Instructional materials involve students in discussions about how to move from one lesson to the next in the storyline. The navigation routine may be used in conjunction with the putting pieces together routine (11.5), to track the progress in the class's current explanations, models or designs and determine what next steps are needed.

13.2.3. Instructional materials include opportunities for public representations of the flow and progress of lessons. The class records their progress in a public representation (such as a progress tracker or summary table) that includes the lesson question or purpose, phenomenon, and what they figured out. Each lesson or set of lessons includes a discussion-based activity to update this public representation. This routing also helps elicit current student understanding throughout the unit and attend to navigation and coherence from the student's perspective. Individual students may also keep a version of this representation in their notebooks.

13.2.4. Transitions between lessons in units (at the closing of a lesson, the opening of the next lesson, or both) contain whole-class navigation discussions to maintain coherence from the students' perspective. The discussions have both a reflective and a prospective element. The reflective element asks students to articulate the question or problem for the lesson and the way the
class decided to investigate it and what they figured out, referencing public representations such as a summary table or progress tracker. The prospective element involves asking students to evaluate their current progress and discuss possible next steps. While the flow from one lesson to the next is anticipated in the unit storyline, these discussions involve students working as partners through the logic of where to go next and maintain the coherence from their perspective.

13.3. Investigation Routine: Using Practices to Figure Out Science Ideas

The purpose of the Investigation routine is to use questions around a phenomenon or engineering problem that lead the class to engage in science and engineering practices to make sense of the phenomenon or solve the problem, and then develop the science ideas as part of the explanation or solution. This is the basic structure of the work of three-dimensional learning. The Investigation routine is conducted throughout the unit, whenever students identify gaps in the models, explanations, or designs they are developing.

13.3.1. Teacher materials guide teachers in helping students to iteratively develop and evaluate their models and solutions, test them for generality, and uncover limitations that lead to productive directions for investigation and revising designs.

13.3.2. Materials support students to create a plan of action, collect data and analyze their results and then make sense of their new understanding and how it fits into their models, explanations, and designs.

13.3.3. Instructional materials provide opportunities for all students to engage in the science and engineering practices and encourages them to use many means of recording and communicating including charts, drawings, graphs, numbers, and images. Instructional materials involve student use of science notebooks where students document their questions, thoughts, ideas, writing, and investigations.

13.3.4. Units contain sequences of phenomena selected to help students develop explanatory models or design solutions, and then uncover questions that lead to either generalizing them or elaborating them to handle the new
cases. For example, after figuring out that instruments and speakers appear to make sound by vibration, students ask whether all objects that make a sound (including very solid objects like floors, walls, and tables) vibrate when they make a sound.

13.3.5. Teacher materials provide supports for teachers to engage students in science and engineering practices through productive talk in small group and whole-class discussions. Teacher supports provide example prompts and strategies to support students’ sense making, building on ideas of others, making their thinking public, and supporting models, explanations, and designs with argument. Example approaches include supports for science talk moves and the strategies in Ambitious Science Teaching. See Chapter 3, especially 3.2, for more details on establishing classroom norms to support productive talk.

13.3.6. Instructional materials include whole class, small group, and student pair discussion activity structures used to support productive science talk, such as Scientists Circles, group norms and roles, or think-pair-share.

13.4. Problematizing Routine: Motivating Students to go Deeper in their Science and Engineering work

The purpose of the Problematizing Routine is to reveal a potential problem with the current model, explanation or design in order to motivate students to extend or revise their work. The teacher seeds, cultivates, and capitalizes on an emerging disagreement that reveals the potential problem and gets students to focus on an important question that could extend their models or designs. The Problematizing routine is often conducted after a Putting Pieces Together routine or at strategic locations where students need to recognize that while they have made progress, there is more to figure out.

13.4.1. Instructional materials include opportunities to create and update public representations of scientific models or designs. Units contain frequent opportunities for students to revise their models or designs, first as individuals or pairs, and then in small groups.

13.4.2. Teacher materials guide teachers in eliciting current student understanding at key points in the unit (not just prior knowledge at the beginning) so that
teachers are aware of the resources that students have drawn on when reasoning about a phenomenon or problem. When teachers elicit and connect to current understanding, students are more likely to experience instruction as coherent and are able to track their progress over time.

13.4.3. Where appropriate, teacher materials guide teachers to help students uncover limitations in their current models or designs and/or focus on important ways their ideas can be extended. This may occur through introducing additional phenomena, a wrinkle in the design problem, or capitalizing on emerging disagreement in explanations or variations in designs.

13.5. Putting Pieces Together Routine: Using the Science Ideas We’ve Built So Far

In the Putting Pieces Together routine, students take the ideas they have developed across multiple lessons and figure out how they can be connected to explain the phenomenon or solve the problem the class is working on. This routine serves to help students take stock of their learning and develop a shared artifact (in their small group or as a whole class) to represent their explanation, model or design.

13.5.1. The Putting Pieces Together routine is conducted at strategic moments when students have synthesized evidence from a range of situations to construct an important component of the explanatory model or a design solution. This is often at the end of a lesson set and at the end of the unit. Students typically represent their thinking through the following:
   - A gotta-have-it checklist
   - A class consensus model
   - A group action plan
   - A design solution

13.5.2. Teachers are provided with discussion strategies to press students for gapless explanations and models. Teachers support students in linking their ideas, from a variety of sources including prior knowledge, into a coherent chain of reasoning which ultimately allows students to put those pieces together into a causal explanation or complete solution to a problem. Instructional materials contain guidelines students can use to evaluate the
coherence and completeness of models, and of explanations derived from models.

13.5.3. At key points when enough evidence has been accumulated, a lesson provides an opportunity for students to compare their models or designs in small groups and attempt to reach consensus. For units focused on explaining phenomena, following the small group consensus-building process, the whole class should develop a class consensus model through discussion, and create a shared, public representation of it. For units focused on engineering design, comparing students’ ideas can help establish shared consensus on the problems they have identified, and explore both commonalities and productive variations in the design solutions they have developed.
Integration of English Language Arts and Mathematics

The goal of integrating English Language Arts (ELA) and mathematics into science Instructional materials is to build a strong base of knowledge through content-rich text and to reinforce science learning through literacy and mathematics connections. This is accomplished through the careful alignment of the science standards and the deep integration of practices from mathematics and ELA that can be used to strengthen the learning and doing of science and engineering. This integration should be driven by what is needed to learn the science and be intentional, not an afterthought.

Developers should examine the CCSS-ELA for specifics that make the most sense to integrate with science, including Figure 4 in Appendix A which details grade-specific text complexity demands and the three types of writing (opinion (similar to argument in grades 6-12), informational/explanatory, and narrative). Note that writing and developing an argument is especially emphasized in CCSS-ELA (and is distinguished from persuasive writing). In addition, the authors stress that oral language used in a purposeful, systematic way is essential to building and improving literacy development.

When considering the CCSS-Mathematics, developers should take note that the elementary standard “Measurement and Data” as well as the standards for mathematical practice offer the greatest opportunities for integration into science learning, especially MP 3: Construct viable arguments and critique the reasoning of others and MP 4: Model with mathematics. See Next Generation Science Standards (NGSS) Appendix L for additional connections to CCSS-M standards.

Others have noted that the increased importance of, and emphasis on, argumentation across all these standards signals a major change in how we think students should learn and how teachers should teach (Stage, Asturias, Cheuk, Daro & Hampton, 2013). Figure 1 (Cheuk, 2012) offers a synthesis of the student practices (and student capacities) from four sets of documents, the Common Core State Standards (CCSS) in English language arts and literacy in history/social studies, science, and technical subjects, CCSS in Mathematics, A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas, and the Framework for English Language Proficiency Development (ELPD) Standards corresponding to the CCSS and NGSS.
Support for integrating English language arts into science classrooms is provided.

The goal of integrating English language arts within units is to use literacy practices of reading, writing, speaking, and listening to develop and reinforce important science ideas and practices, while supporting students in strengthening their English language arts.
practices, extending their vocabulary, and demonstrating the importance of language practices for science.

14.1.1. Instructional materials are intentional in their placement and purpose of text. Text is placed within the unit at key junctures where students need to gather information to motivate the storyline, better understand a concept, or work through an investigation. (Note in the early elementary grades, teacher read-aloud may be the more appropriate means for students to access textual material.) Generally, students experience a concept in some way prior to reading about it, allowing them to make a connection between their experience of a concept and scientific information in the text and develop knowledge about the concept. Text that introduces a phenomenon to students is adapted for classroom use and intended to engage students into the storyline (for example, a doctor’s note, a fictional story, a child's diary entry, a text message exchange). Some text is just in time to help the storyline along, to support students in generating questions or ideas, to help to clarify some piece of the puzzle students are figuring out, or to give students language to describe what they are seeing.

14.1.2. Instructional materials are intentional in the variety and complexity of text and aligned with CCSS-ELA in doing so. Units include text from a variety of sources that require students to interpret key science ideas from the text (such as words, graphs, images, illustrations, photographs, newspapers, digital sources and other media). Instructional materials include a mix of authentic science sources adapted for classroom use in differentiated ways to meet individual student needs as well as trade books, historical, and informational texts matched to the storyline of the unit. (Note the resource NewsELA is one that offers content information at multiple reading levels. This service is not free, but many districts subscribe to it.)

14.1.3. At each grade level, students have opportunities to analyze textual material using strategies drawn from Common Core State Standards. Graphic organizers and prompts are especially helpful for students and teachers and should be integrated into the instructional materials. Ideally some of these organizers will be similar to the tools teachers already use in ELA instruction.
14.1.4. Learning goals and objectives related to CCSS-ELA and CCSS-M are explicitly noted in units and lesson plans.

14.1.5. Instructional materials are intentional about the purpose, placement, and variety of written work. Units incorporate a student science notebook and additional written student work on a daily basis for students to write, draw, and communicate their understanding of science ideas and practices. Teacher materials will include guidance on how to support student growth from informal (everyday) language describing science ideas to the strategic use of discipline-specific language. Written work integrates standards for writing from the CCSS-ELA as well as relevant mathematical practices from CCSS-M. Students are provided opportunities to metacognitively reflect on their writing and their reasoning.

14.1.6. Materials integrate the use of a science notebook. The notebook is a place to gather evidence, ideas, thoughts, questions, etc. and is intentionally not evaluated. Lessons should support teachers and students with strategies to use the notebook data to create separate and more formal explanations of phenomena. These opportunities should include rubrics so these products can be graded or evaluated while the notebook would not be evaluated.

14.1.7. Teacher materials provide support and modifications for students with special learning needs, by providing students with multiple means of engagement, representation, and expression to include digital tools such as Google or PowerPoint slides, video apps such as FlipGrid, and so on.

14.1.8. Materials use translanguaging approaches that create opportunities for multilingual students to engage in science and engineering practices while fluidly leveraging the multiple languages they speak. (See Chapter 4 for specifications related to multilingual learners.)

14.1.9. In the course of doing science and engineering, students will frequently engage in speaking, listening, and responding to others. The instructional materials will provide guidance and rubrics aligned to CCSS-ELA for speaking and listening, including standards for comprehension and collaboration, and presentation of knowledge and ideas.
14.1.10. Student advocacy for ideas and willingness to consider their peers differing perspectives must be fostered in the instructional materials and core the classroom instruction. Materials should support teachers to apply group protocols they may have in place from ELA or mathematics as appropriate for science lessons.

14.2. Support for the integration of mathematics into science classrooms is provided.

The mathematics relied upon in science lessons should be integrated and used to support the understanding and doing of the science. Units that incorporate mathematics should focus on ideas and skills that students have learned in previous grade levels. When applying mathematics, materials connect to and reinforce the CCSS-M.

14.2.1. Instructional materials are intentional in their placement and purpose of mathematics content. Mathematics is intended to help the storyline along, clarify pieces of the puzzle students are figuring out, or provide students with tools to highlight, analyze, model, and interpret important patterns in the data they are exploring. Mathematical practices will be employed to develop student understanding of science ideas and deepen science practices.

14.2.2. Teacher supports are provided for leveraging multiple ways of student thinking, connecting, and representing their mathematical ideas, both in investigations that are targeting the use of those mathematical ideas and in those where it is likely that some students may bring them in.

14.2.3. Teacher materials provide support and modifications for students with special learning needs related to mathematics. Fluency with specific mathematical procedures should not derail the conceptual understanding or application of the science content. For example, they may provide alternate student prompts or partially filled-in data sheets to provide opportunities for students to engage with mathematics conceptually prior to quantitatively. Instructional materials embed scaffolds to help students break down the use of mathematics into manageable parts and use multiple representations and manipulatives of mathematics concepts to help reinforce mathematical concepts or reasoning. Teacher materials provide support to break down analysis of the data into smaller steps or explain the problem in a different
way. Students are provided the opportunity to explore, evaluate, and learn from multiple mathematical approaches when employed.

14.2.4. Instructional materials are intentional in their placement and leveraging of student work applying MP 5: Use appropriate tools strategically. The tools (models, measurement devices, spreadsheets, software, etc.) that students used in prior grade levels to learn and apply mathematics should be leveraged to support the learning and doing of science.

References


15-Meeting Practical Needs and Constraints of Public Education

An important risk in efforts to transform educational practices and improve outcomes is to overlook the importance of practicality. In the rush to incorporate attributes that are known to support transformation and improvement, programs must make sure that it is practically possible and realistic for teachers to implement in order to bring about real and lasting change. Practicality is contextual. The thresholds for what makes a program too challenging or infeasible depend on the social capital and material resources that are available in a particular setting. Therefore, the design specifications for practicality have been designed in consultation with core state partners to fit the contexts in their states.

15.1. Instructional materials are convenient and usable by the largest possible audience. Consideration must also be given to schools and districts that are not able to budget large amounts for printing so that equitable distribution of the materials is possible.

15.1.1. Student print materials consist of a full-color, non-consumable student edition and a set of black-and-white, consumable student handouts to be distributed for students to write on. Digital versions are also available. Students are provided or asked to supply a science notebook as a persistent space for them to record and organize their work.

15.1.2. Student materials should be available in multiple languages. These materials should be developed through field testing in these languages, not via after-the-fact translations.

15.1.3. Teacher print materials consist of a full-color teacher guide that is bound to lay flat. Teachers are also provided a digital version formatted for a laptop or tablet that supports printing. Teacher materials include presentation slides for each lesson to help with structuring discussions and activities.

15.2. The materials are designed so there is time in every school day to engage elementary students in high-quality science instruction that actively involves them in the practices of science.

We note that neither NSTA or we found a research basis for recommending a specific number of minutes for teaching core content, including science. However, many states, districts, and schools currently prescribe a set number of minutes—either by day, week, or year. As a result of this practice, science receives far less instruction time than other core
subjects (Horizon Research 2013). NSTA recommends that science be given equal priority as other core subjects, so schools should strive for at least 60 minutes of science instruction a day, including significant science investigations.

15.2.1. Materials should offer lessons that can be completed in 20-30 minutes/day at K-2 and 45-60 minutes/day at grades 3-5, keeping in mind the recommendation from NSTA.

15.2.2. Instructional material must also guide teachers in supporting students who are or have been absent from class with home activities and/or readings intended to help absent students maintain progress with their classmates while remaining true to the storyline instructional model. For instance, investigations could have a video or simulation version or home adaptation from which students can gather data.

15.3. Computational technology supports three-dimensional science learning, within school constraints.

Instructional materials seek to take advantage of the benefits of computational technology to support three-dimensional science learning, while conforming to the practical constraints of current schools. We recommend looking at the Technology Integration Practices (TIP) Guide for forward looking ways to integrate technology in ways that support students to engage in content and scientific practices in equitable ways.

15.3.1. Instructional materials can assume that every classroom has a dedicated device that can project on a screen or display that is large enough for the entire class to see, and has an internet connection that is fast enough to support video streaming. The instructional materials may call for interactive use of computers, Chromebooks, or tablets by students in a ratio of 2 students per device, as long as those activities can also be done as a whole class or as one station that students rotate through during a class session. To manage the inequities that persist in the distribution of devices, materials must also include alternative approaches that are of high quality for learning.
15.3.2. To accommodate teachers who need to schedule device carts or technology labs, interactive activities require no more than 2 consecutive class periods of instruction.

15.4. Instructional materials seek to provide students with the greatest possible opportunity to engage in scientific and engineering practices with appropriate tools and techniques, within the practical constraints of current schools.

15.4.1. Instructional materials may require consumable supplies and non-standard equipment that can be purchased for less than $400 for each unit on average. The cost of replenishable supplies to implement a unit in subsequent years average less than $80 for grade level each year.

15.4.2. Instructional materials do not assume that teachers have access to a laboratory setting, sink, or multiple electrical outlets in the classroom.

15.4.3. Materials assume that there are flat surfaces available such as tables or countertops.

References


16—Guidance on Modifying Instructional Units

OpenSciEd instructional materials are designed as an Open Educational Resource with the explicit goal of supporting the adaptation and customization of the program for different goals and circumstances. As the design includes building understanding and abilities over time, the units and the lessons within units are intended to be taught in a specific order. Modifications to the sequence of units or the contents of units could undermine the design.

To enable adaptation and customization of the program without undermining the design, guidance is provided to those who might modify the units. The materials will make teachers and curriculum coordinators aware of the implications of potential changes and are provided with information that will allow them to make changes in a way that still achieves the goals of the program. Teacher materials describe the dependencies within the program and with other content areas as well as provide a clear rationale behind the sequence and design of materials in the program. Informing educators of these dependencies and rationale helps to avoid modifying the materials in ways that are detrimental to student learning. Teacher materials also provide teachers with information about pacing of the materials (including where activities could be compressed or extended) to help with avoiding a breakdown in the storyline for students. Information on which learning goals are emphasized at key parts of the materials allows teachers to make informed decisions about supplementing materials or customizing those materials for a particular student audience.

16.1. Support for modifying unit sequences is provided.

16.1.1. To allow educators to change the sequencing of units, instructional materials document how concepts and practices are developed over time and across units. This documentation provides information about how a unit depends on previous units and how it supports subsequent units, about the prerequisite knowledge (science, math, and ELA) necessary for each unit and what actions are necessary to supplement this knowledge if the unit is taught out of the designed sequence, and about how future units may be impacted if the unit changes in the sequence.

16.1.2. According to Horizon Research only 18 percent of primary grades classes and 26 percent of intermediate grades classes receive science instruction all or most days every week of the school year. The large majority of elementary
classes receive science instruction only a few days a week or during some, but not all, weeks of the year. With this in mind, the instructional materials should provide support to teachers and curriculum specialists about how to choose and sequence units to meet a variety of instructional schedules with clear information about what the tradeoffs for learning goals are.

16.2. Support for modifying unit storylines is provided.

16.2.1. To allow educators to customize the storyline for specific locations or populations, instructional materials document how the central task and/or phenomenon connects the learning goals of individual activities into a coherent storyline.

16.2.2. Units include and document opportunities to locally frame the phenomena or design problems for students and to continually make connections to the students’ lived experiences in their community.

16.3. Support for modifying activities is provided.

16.3.1. To allow educators to modify or replace individual activities, instructional materials document the learning goals for each activity. Learning goals for each lesson are clearly stated within the teacher materials, allowing educators to determine whether switching or supplementing the lesson with a different activity is appropriate or not.

16.4. Support for science specialists and/or Co-teaching

16.4.1. Instructional materials provide modifications, strategies and scaffolds that support science teaching in various contexts.

References

Credits
This document is a refinement of both the OpenSciEd Middle School and High School Design Specifications. These refinements were made to optimize these specifications for the elementary school context and reflect research at that level.

The chapters in this volume are based on those originally developed by collaborative teams for the Middle School Design Specifications. For that process, each team had one or two designated leads and several members selected for their expertise by OpenSciEd Developer Consortium and State Steering Committee members. Their work was coordinated by Daniel Edelson and Audrey Mohan of BSCS Science Learning and the team members are noted below. Final editing was conducted by OpenSciEd.

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