Version 2.0

Teacher Handbook

OpenSciEd

MIDDLE SCHOOL SCIENCE

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Beta Version 2.0
August 2019

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Contents

About the OpenSciEd Teacher Handbook

The OpenSciEd Project is a revolutionary effort to implement the recommendations of the National Research Council in its 2012 *Framework for K–12 Science Education (National Research Council, 2012)*, as embodied in the science standards of the more than 35 states who have used the NRC Framework and the Next Generation Science Standards (NGSS Lead States, 2013) to inform their standards writing processes. The objective of the OpenSciEd Project is to create and disseminate instructional materials that implement the approach to science teaching and learning that has come to be known as *three-dimensional science learning* since the release of these documents.

To achieve this objective, OpenSciEd calls for teaching practices that have not been part of the repertoire of most science teachers historically. While the OpenSciEd units are designed to provide teachers who are new to three-dimensional learning with enough support to implement the units successfully, this *OpenSciEd Teacher Handbook* provides overviews of features of the OpenSciEd units that are likely to be new to many teachers. Each chapter focuses on a different feature.

The *Handbook* is not designed to be read from front to back. We envision that teachers will read some chapters as an introduction to the OpenSciEd approach as they begin to plan for instruction, and will choose to read others on an as-needed basis as they go through the planning process. Most important, the *Handbook* is designed to be a resource that teachers can refer back to at any time.

The *Handbook* is neither a comprehensive reference on the OpenSciEd program nor a tutorial on how to implement the teaching practices of the program. The OpenSciEd developers believe that such resources have limited utility. Ultimately, we believe that teachers learn new practices by doing—through the acts of planning, implementing, reflecting, and replanning. We envision this *Handbook* as one support for that learning-by-doing process, ideally in combination with other informational resources, peers, and experts.

A. The OpenSciEd Instructional Approach

OpenSciEd units are designed using a form of "science storyline" approach. The goal of a science storyline approach is to provide students with a coherent experience that is motivated by the students' own desire to explain something they don't understand or to solve a problem (Reiser, Novak, & McGill, 2017). We use the metaphor of a storyline to capture the fact that learners should be motivated to work through the next step in a science unit just as they are motivated to see what happens next in an unfolding story.

An OpenSciEd unit storyline is a logical sequence of lessons that are motivated by students' questions. It is a science storyline because the questions arise from students' interactions with phenomena. OpenSciEd storylines are designed to provide students with the goal of explaining a phenomenon and/or solving a problem. Each step is designed to enable students to make progress on their questions by using science and engineering practices to help figure out a piece of a science idea. Each piece they figure out adds to the developing explanation, model, or designed solution. Each step may also generate new questions that add to students' work in the storyline. As a step-wise process of questioning, investigating, and building understanding, a storyline provides a coherent path toward building a disciplinary core idea and cross-cutting concepts, anchored in students' own experiences and questions.

Why use Science Storylines to Organize OpenSciEd Units?

In traditional approaches to science teaching, units are sequenced based on how experts understand the relationship among concepts. This means that it typically requires an understanding of the concepts being taught to understand why a unit is sequenced the way it is. The result is that the sequence of activities may make sense to a teacher, but doesn't necessarily make sense to the students. For example, a teacher may understand how certain activities to learn about cells will help students understand important biological concepts, but students may only know that they are learning about cells because that's the title of the current chapter in the textbook. Or a teacher may know how a particular chemistry experiment demonstrates something about conservation of matter, but the only reason her students may have for doing that experiment is that it is part of their assignment from the teacher.

In the science storyline approach used in OpenSciEd, the sequence of activities is designed to make sense to students. We call that "coherence from the students' perspective." When a storyline is coherent from the student perspective, a visitor to the classroom on any given day should be able to walk over to a group of students and ask them why they are doing what they are doing and receive an answer that describes a question they are trying to figure out or a problem they are trying to solve.

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There are four key considerations in the OpenSciEd instructional approach:
- Phenomena
- Disciplinary core ideas
- Science and engineering practices
- Crosscutting concepts

The disciplinary core ideas, science and engineering practices, and crosscutting concepts reflect the *Framework for K–12 Science Education* and the performance expectations embodied by the Next Generation Science Standards and the standards of the more than 35 states who have used these documents to inform their state science standards.

What is the role of phenomena in OpenSciEd?

Interesting phenomena are key to the OpenSciEd storyline approach. Ultimately, every storyline is a journey to figuring out a phenomenon that defies easy explanation. It might be a surprising or puzzling phenomenon, something that violates the rules of the world that students have come to accept, like an object that levitates. It might be a phenomenon students need to understand to address a problem, such as predicting and preparing for a violent storm. It might be a phenomenon that they want to know how to control, like soil erosion on a farm. Or, it might be an everyday phenomenon that mystifies students when they stop to think about it, like why droplets of water spontaneously appear on the outside of a glass of cold water.

In OpenSciEd units, phenomena are carefully selected to anchor a storyline, and to motivate the development of target disciplinary core ideas, crosscutting concepts, and science and engineering practices. These *anchoring phenomena* are used to draw students into the storyline by presenting the natural challenge of explaining something or solving a problem. Other phenomena may be introduced at key points in a storyline to maintain interest or push students to delve more deeply.

What is the role of the disciplinary core ideas in OpenSciEd?

In OpenSciEd, students use disciplinary core ideas (DCIs) to make sense of how and why phenomena occur. OpenSciEd units are designed to help students draw on DCIs developed in the prior grade bands (K-5) and in prior units, and to extend these ideas piece by piece as the unit progresses. OpenSciEd lessons call out which elements of the DCIs are targeted in each lesson and identify new aspects of these ideas students begin to develop in the lesson. The unit overview and teacher background section for each unit explains the progression through which DCIs are incrementally developed and extended through the unit. The OpenSciEd Scope and Sequence provides a pathway through which students can coherently build the target DCIs across three years of middle school, drawing on and revising ideas built in prior units.

What is the role of the science and engineering practices in OpenSciEd?

In OpenSciEd, science and engineering practices (SEPs) provide the avenue by which students develop new ideas and make new discoveries throughout the storyline. They use questioning to articulate what they need to figure out. They investigate to generate new ideas about why things work the way they do or to test their

conjectures. They construct models and explanations to organize their ideas and share them with others. Science and engineering practices guide the work with phenomena and problems so students can develop, test, and refine science ideas. Modeling and argumentation are particularly important practices in the early OpenSciEd units and have additional supports available. See section E of this handbook for more discussion on Science and Engineering practices, and particular, modeling and argumentation.

What is the role of the crosscutting concepts in OpenSciEd?

In OpenSciEd units, the crosscutting concepts (CCCs) are used to support student sensemaking in three general ways:
- by providing a scaffold to ask productive and investigable questions,
- as a set of principles and heuristics to guide model building and explanation, and
- as a way to frame the sequence students' experiences of related phenomena in ways that engage students in analogical reasoning.

The CCCs are developed and used strategic to help students make connections within and across units and intentionally transition from highly scaffolded experiences with CCCs applied to curated phenomena (e.g., applying a rubric that highlights CCCs to students' models of a phenomenon) to limited scaffolding with uncurated phenomena (e.g., students apply ideas of matter and energy to a related phenomenon at the end of a unit).

In summary, each OpenSciEd unit is anchored in a phenomenon or set of phenomena, and strategically integrates the DCIs, SEPs and CCCs to create a storyline path in which the students and teachers, as a learning community, work together to manage the trajectory of their knowledge building. The class, as a whole, incrementally develops ideas over time, motivated by questions about phenomena in the world, where each step is an attempt to address a question or a gap in the class's current explanatory model, developing, using, and extending parts of the DCIs, SEPs, and CCCs as needed. The storyline approach supports students' agency in sensemaking: WE figure out the science ideas and WE put those ideas together over time.

B. Organization of OpenSciEd Units

OpenSciEd units are organized into collections of lessons called *lesson sets.* Each lesson set advances the storyline by investigating one aspect of the anchoring phenomenon. Each lesson set in an OpenSciEd unit is an inquiry cycle in which students pose questions about some aspect of a phenomenon, explore the phenomenon through scientific investigations, and then work to make sense of their observations. At the end of a lesson set, students put their ideas together to express a more complete or sophisticated understanding of the phenomenon than they entered the lesson set with.

A lesson set is made up of individual lessons, each of which has several parts, or *activities*, that work together to help students make sense of some phenomenon or problem. Lessons range in length from one class period to several. To help you understand the organization of the units, here is a generic structure of an individual unit*:

> Unit: Unit Driving Question (i.e., the unit title)
> - Lesson Set 1
>   - Lesson 1: Anchoring Phenomenon and Driving Question Board
>   - Activity 1: Name of Activity...
>   - Activity 2: Name of Activity...
>   - Lesson 2: Investigation
>   - Lesson 3: Investigation
>   - Lesson 4: Putting Pieces Together and Problematizing
> - Lesson Set 2: Lesson Driving Question
>   - Lesson 5...

*See sections A and C for more information about the instructional model.

Each OpenSciEd unit has several components. For teachers, there is a **teacher edition** for each unit that describes the lesson procedures and instructional strategies, including key ideas for teachers to emphasize in each lesson. These guides are comprehensive, including example questions to ask at particular points in the lesson and example student responses. These guides are not intended to be used as a script but rather as suggestions for how to implement the lessons, which teachers can start with in planning instruction for their specific settings and students. Teachers are also provided with **additional lesson resources**, such as lab instructions, keys and rubrics, as appropriate for the lesson, and each lesson has an **editable set of presentation slides and google docs** that teachers can project and use as they move through each lesson.

Each unit also comes with a **student edition**, which provides readings, references, and lesson procedures. In addition to this student edition, there are **student handouts** designed for situations where students need to draw or write on an image or graphic organizer. These handouts need to be copied for each student. Students also have access to **interactive resources**, such as simulations, to interact with as they are figuring out science ideas. Finally, all students need to have a **science notebook** to use for written work throughout the unit.

C. OpenSciEd Routines

To help teachers and students advance through a unit storyline, OpenSciEd takes advantage of routines—activities that play specific roles in advancing the storyline with structures to help students achieve the objectives of those activities.

OpenSciEd units use five routines drawn from the work of the NextGen Science Storylines Project (Reiser, Novak, McGill, 2017):

Routine	Purpose
Anchoring Phenomenon routine	Develop curiosity to drive learning throughout the unit based on a common experience of a phenomenon and connections to any related phenomena students have experienced.
Navigation routine	Establish and reinforce the connections between what we have previously done in a unit, what we are about to do, what we will do in the future, and what our driving purpose is in the context of the unit.
Investigation routine	Use scientific practices to investigate and make sense of a phenomenon.
Putting Pieces Together routine	Take the pieces of ideas we have developed across multiple lessons and figure out how they can be connected together to account for the phenomenon we have been working on.
Problematizing routine	Evaluate the adequacy of our scientific ideas to explain a phenomenon in order to identify what we still need to understand.

How and where the routines are found will vary somewhat across the units in OpenSciEd, but these routines typically follow a pattern as students kick off a unit of study, investigate different questions they have, put the pieces together from those investigations, and then problematize the next set of questions to investigate. Each unit will have a slight variation on what happens within a particular routine, based on the anchoring phenomenon and the focal SEPs and CCCs, but the purpose and general approach of the routine is consistent across all units. The OpenSciEd Instructional Model on the following page provides a general path through an OpenSciEd unit using the routines. Note: the Navigation Routine is something that occurs from lesson-to-lesson and is not on the model, but described more fully below.

OpenSciEd Instructional Model

We share an experience.

PHENOMENON

Anchoring Phenomenon Routine

We develop questions for the Driving Question Board.

Investigation Routine

We gather evidence from investigations, videos interactives, readings, and other data sources.

Putting The Pieces Together Routine

We come to a consensus on what we've figured out so far.

Problematizing Routine

Investigation Routine

But new questions emerge through evidence we find.

We gather more evidence.

We come to a consensus on what we've figured out, and have a more complete explanation of the phenomenon.

Putting The Pieces Together Routine

We've answered many of the questions from our Driving Question Board.

Anchoring Phenomenon Routine
Kicking off a Unit with an Experience to Motivate Investigation

What is it, and what is its purpose?
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 capture students' initial ideas as a pre-assessment opportunity.

The Anchoring Phenomenon routine
- creates an opportunity for students to voice their initial ideas about the phenomenon;
- identifies the areas of agreement and disagreement in students' ideas about the mechanisms behind one or more aspects of the phenomenon;
- exposes to the teacher what students do and do not know about these mechanisms; and
- elicits questions that the students want to investigate and answer throughout the unit, which the teacher will be able to use to motivate students and connect the lessons in the unit.

When is it done within a unit?
The Anchoring Phenomenon is introduced at the beginning of a unit.

How do students typically represent their thinking as part of the routine?
The Anchoring Phenomenon routine pushes students to represent their initial thinking by writing, drawing, and sharing their own initial models, explanations, or design solutions. These might be represented in their science notebooks. In the Anchoring Phenomenon routine, students also create a shared classroom representation of an initial class consensus model, a Driving Question Board, and ideas for potential investigations (all discussed in this handbook).

Typical Elements of the Anchoring Phenomenon Routine

Element 1: Explore the Anchoring Phenomenon
Every OpenSciEd unit starts with a puzzling phenomenon that students experience and explore in some way. In this initial exploration, the question the class focuses on is, "What do we notice?" For example, students might make observations, look for patterns, or create a timeline of events that occurred. The purpose of this element is for students to recognize the interesting events going on and to publicly, as a learning community, acknowledge aspects of the phenomenon that requires explanation.

Element 2: Attempt to Make Sense
In the "making sense" element, students try to come up with an explanation, model, or some other reasoning to explain why or how the phenomenon under investigation is happening. The point of this element is for students to voice their initial ideas about the phenomenon, no matter how inaccurate or far-fetched they may be. The purpose is to lay a foundation for the investigations they will conduct throughout the unit that

will lead them to a scientific understanding. By trying to make sense of the phenomenon themselves, students generate ideas that lead to questions and theories that they will want to investigate.

It's important that each student tries individually to make sense of the phenomenon and then go public with his or her ideas. Diversity in our sensemaking ideas is very productive! It helps create the sense that we are all not on the same page, and that there are things here that beg to be figured out. The role of the teacher in this part of the routine is twofold: (1) to help students get their thinking down on the page, regardless of whether it's right or wrong and (2) to push students to come up with a mechanistic explanation about what's going on. Press students to go deeper if they think they know the answer. More likely than not, even students who use correct vocabulary to explain what they think is going on cannot really tell you what those words mean in a mechanistic way.

An example sequence of this element follows:
- individual sensemaking first (e.g., developing a model in their science notebooks)
- intermediate sensemaking (e.g., considering how their own model compares to another's—it can be done with a partner, small group, or gallery walk)
- class sensemaking conversation and initial consensus model

Element 3: Identify Related Phenomena
The goal of OpenSciEd units isn't just to solve a single mystery about one phenomenon. The goal is to build up disciplinary core ideas and cross-cutting concepts that can be applied to a range of events in our world. The purpose of having students identify related phenomena is to broaden the scope of what the class is really interested in figuring out and for students to have a personal connection and investment to the events being explored in class.

An example sequence of this element follows:
- Students write in their notebooks about related phenomena from their personal experience.
- Students have an opportunity to share their experience with classmates.
- The class may create a public representation of students' ideas to organize students' sharing of related phenomena and get students to attend to certain features (patterns) across related phenomena (if it makes sense).

Element 4: Pose Questions to Resolve and Discuss Next Steps
In the fourth element, the class uses a Driving Question Board (DQB) to create a joint list of questions and action items to help understand the anchoring phenomenon. What's unique about three-dimensional learning is the opportunity for students to be involved in the thought process and decision-making about what the class should be figuring out and how the class should be figuring it out. It is important for each student to participate in generating a question to be explored and for those questions to be made public so that the class, as a whole, retains ownership of those questions. Similarly, students should be involved in thinking about ways to go about answering one or more of the questions from the class. The point of doing this is so students are identifying actionable ways to figure out answers to their questions. For example, the class thinks a good way to follow up on one of the questions is to look up what experts have to say or to gather secondhand data. The goal isn't to come up with the perfect question or solution. Questions and next steps will be revised, revisited, and checked off as the unit progresses.

An example sequence of this element follows:
- The teacher asks, "What do we want to know next?"
  - Students write individual questions.
  - Students share questions aloud.
  - The class organizes the questions on the DQB.
- The teacher asks, "What do we want to do next?"
  - Students brainstorm investigations that could help them figure out their questions, and why the investigations might help.
  - Post their ideas near the DQB.

Navigation Routine
Motivating the Next Step in an Investigation

What is it, and what is its purpose?
The Navigation routine enables 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.

When is it conducted?
The Navigation routine is conducted throughout the unit at transition points.

How do students typically represent their thinking as part of the routine?
The Navigation routine is all about linking learning across lessons and activities. Students might represent their thinking in the following ways:
- Revisiting their initial ideas and focus questions in their science notebooks
- Revisiting their individual models in their notebooks to add to or revise their thinking
- Recording a "consensus" model, using a Progress Tracker, in their notebooks and publicly in the classroom
- Returning to the Driving Question Board to answer questions, add new questions, or refine their questions

Typical Elements of the Navigation Routine

Element 1: Look Back: How did we get here?
- **Routine at the start of a new lesson:** At the beginning of each lesson, the class asks, "What brought us to this point?" The learning community needs to look back and remind themselves: "Where are we in our mission? What have we accomplished? What's the main thing we need to work on now? What was our question?" Oftentimes instructional materials prompt teachers or students to recall where the class left off. Although the teacher may have to start the conversation, the work of reflecting should be done by the students as much as possible.

Element 2: Take Stock: Where are we now?

There are many time points during a lesson that the class might be able to assess where it currently is in the lesson to strengthen connections between activities and the storyline. These time points include the following:

- **Routine in the middle of a lesson, during or between activities:** Throughout the lesson, students should continue to engage in making connections between what they are doing, where they have been, and where they are going. It is easy to lose track of the larger storyline in the midst of an interesting hands-on activity. The teacher engages students in thinking about what they are doing and what it has to do with the bigger questions they are trying to answer in between activities, and during the activity itself.
- **Routine at the end of a day when a lesson isn't complete:** Often class time ends before a lesson is complete. At this point students and the teacher should take stock of where they are in the learning—what they accomplished in that class that helps them answer the driving question and where they will go during the next class. This could be as simple as students (and/or the teacher) making a summary statement at the end of class, but it should be a whole-class statement with some individual student thinking time.
- **Routine to pick up the next day to finish an incomplete lesson:** When a lesson picks back up at the start of a new class period, students need the opportunity to reflect on where they left off in the previous class period, what they were trying to figure out, and where they need to pick back up in their work.

Element 3: Look Forward: Where are we going?

- **Routine at the end of a lesson:** Each lesson ends with another reflection or a look back, where the class asks: "Where are we in our mission? What have we accomplished in this lesson? What's the main thing we need to work on now? What was our question?" After the class has a chance to think about these kinds of questions, it asks, "Where do we need to go next?" When the class looks forward, the students, together with their teacher, talk through the next question or direction to pursue. Involving students in this work is critical for helping them develop into problem-solvers and to position students as partners in figuring out how the world works.

Example strategies in OpenSciEd lessons for the Navigation Routine include:

- Review data from previous class exit tickets.
- Brainstorm related experiences connected to what the class will do that day.
- Use a home learning assignment from the previous class focused on noticings or wonderings, their home observations of some phenomenon, or to pull in new ideas the class will need that day.
- At the start of class, meet at the DQB to identify where the class left off the previous class period.
- Use the Progress Tracker individually, in partners, or small groups to track progress toward answering a question.
- Give one minute of silent thinking and writing time to jot down what the class figured previously and share with a partner and/or whole class.
- Check in on classroom norms to prepare for group work or consensus discussions that will occur or did occur that day.

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Investigation Routine
Using Practices to Figure Out Science Ideas

What is it, and what is its purpose?
The purpose of the Investigation routine is to use questions around a phenomenon that lead the class to engage in science practices to make sense of the phenomenon, and then develop the science ideas as part of the explanation. This is the basic structure of the work of three-dimensional learning.

When is it conducted?
The Investigation routine is conducted throughout the unit, whenever students identify gaps in their understanding of the Anchoring Phenomenon.

How do students typically represent their thinking as part of the routine?
Students represent their thinking during Investigation routines in many different ways, including these:
- Developing a plan of action
- Recording observations and measurements
- Organizing evidence
- Articulating new ideas and comparing them to current models
- Revising models
- Revising the Driving Question Board

Typical Elements of the Investigation Routine

The Investigation routine is the primary routine that students use when they are in the middle of activities trying to figure out something or design solutions to a problem. This routine has three elements to help set up an activity, do the activity, and follow up on the activity.

Element 1: Create a Plan of Action
In the first element, the class works together to articulate a plan of action for investigating a particular question or to discuss why certain things might be measured or attended to during an investigation. This element helps the class figure out their question. Examples of questions that guide the plan include the following:
- How do we plan an investigation?
- What variables do we need to measure and control
- What do we need to focus on in our observations?
- How are we going to record our observations?
- What do different components represent in the real world?
- What do we think might happen?

Element 2: Do the Work with Science and Engineering Practices
Students use science and engineering practices to make sense of a puzzling phenomenon and answer a question—such as carrying out investigations, analyzing data, modeling, and argumentation to make progress on their explanations. The bulk of the class's time and energy is spent in this element. Students should be doing the heavy lifting of figuring out. For example, if you ask students what they are doing at any moment in

the 'doing the activity, then they should identify a phenomenon they are trying to figure out or a question they need to answer. Examples include the following:

- Collecting data through hands-on or computer simulations
- Analyzing graphs or data
- Examining and critiquing evidence
- Observing and manipulating physical models to explain phenomena
- Comparing how well competing models can fit and explain our data

Element 3: Make Sense: What did we figure out?
At each step students assemble another piece of the puzzle through the process of summarizing and synthesizing new information about a phenomenon. It might be a piece of a disciplinary core idea, such as the idea that a vibrating object can make sound. They may also be extending their ideas of cross-cutting concepts such as matter and energy. Notice that students didn't learn about the science ideas first, and then engage in practices to use those science ideas to explain a phenomenon; it was the reverse. Examples include the following:

- Revising or refining a model
- Participating in a consensus discussion (e.g., expressing agreement or disagreement with the ideas or findings of others)
- Revisiting the Driving Question Board (e.g., students ask, "How did it help us answer *X* question?"; this may overlap with the Navigation routine.)

Putting Pieces Together Routine
Using the Science Ideas We've Built So Far

What is it, and what is its purpose?
In the Putting Pieces Together routine, students take the pieces of ideas they have developed across multiple lessons and figure out how they can be connected to account for the phenomenon the class is working on. This routine serves to help students take stock of their learning and engage with the class to develop a consensus representation, explanation, or model to account for the target phenomenon (the phenomenon anchoring the unit or learning set).

When is it conducted?
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. This is often at the end of a lesson set and at the end of the unit.

How do students typically represent their thinking as part of the routine?
Students typically represent their thinking through the following:

- A gotta-have-it checklist
- A class consensus model

Typical Elements of the Putting Pieces Together Routine

Element 1: Take Stock
The first element focuses on taking stock of the main science ideas the class has figured out so far. This could take different forms. First, students need time to reflect on what it is that they are trying to figure out. Then students need to determine which information they've gathered so far might be helpful for them. Students might highlight in their science notebooks the important discoveries they made or revisit their Model Trackers. Or they might refer back to a series of posters of scientific principles that the class has been adding to, lesson by lesson, to keep track of their discoveries over time. The purpose of this element is to get all the pieces of the puzzle out on the table.

Element 2: Put Pieces Together
The second element of the routine involves three parts:
1. Students attempt to put the ideas in the *Gotta-Have-It Checklist* to explain the phenomenon or design a solution, working individually first so that all students are given the opportunity to synthesize the evidence and formulate their ideas. This part is important so that all students are prepared to defend their ideas, evaluate one another's ideas, and consider their ideas in the context of other's ideas.
2. Students share and revise their ideas with a partner or in small groups to surface areas we agree we want to see represented in the class consensus model. This step is important to ensure that all students have the opportunity to articulate their ideas to someone else to help deepen their understanding and begin the process of considering their ideas in the context of other's ideas. This also creates a safer space for students who might be less willing to participate in a larger setting. In addition, this helps the partners or small groups identify ideas or features they want to bring to the class consensus model.
3. The class has a *consensus-building discussion* where students draw on their work to share and evaluate alternate models or explanations and to contribute to the *Gotta-Have-It Checklist* to explain a phenomenon or design a solution. During this process, the class develops a public representation of the ideas as they are putting them together, such as a diagrammatic model, a table showing commonalities across a series of cases, or a written explanation. The result is a revised class consensus model.

Element 3: Revisit the Driving Question Board
Depending on when this routine happens in the unit, students may consider what puzzle pieces they have just put together, take stock of what they have figured out, and then revisit the questions on the Driving Question Board. This move can motivate them to identify what further questions need to be investigated as the class moves into the next lesson set.

Element 4: Apply This to Another Phenomenon (Optional)
Sometimes the class is ready to go further, and there may be a fourth element of this routine. After the class comes to a consensus on a public representation of how the pieces fit together, and students feel confident about the model, they may attempt to explain new phenomena or solve a new problem. They may learn additional ideas that might be useful for explaining the phenomenon and consider the generalizability of their ideas.

Problematizing Routine
Motivating Learning through Each Part of a Unit

What is it, and what is its purpose?

The purpose of the Problematizing routine is to reveal a potential problem with the current model or explanation in order to motivate students to extend or revise their models. 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.

When is it conducted?

The Problematizing routine is often conducted after a Putting Pieces Together routine or at strategic locations where we need students to recognize that there is more to figure out.

Typical Elements of the Problematizing Routine

The Problematizing routine has a great deal in common with the Anchoring Phenomenon routine. Both routines are about helping students see that there are aspects of a phenomenon that they are unable to explain. Whereas the Anchoring Phenomenon routine presents students with the puzzling aspects of a phenomenon for the first time, the Problematizing routine typically focuses on a phenomenon that students are already familiar with, but it presents them with aspects of the phenomenon that they have not yet figured out how to explain. Therefore, the first element that appears in the routine typically is different from the element in the Anchoring Phenomenon routine, but the elements that follow are typically the same as those in the Anchoring Phenomenon routine.

Element 1: Identify Aspects of the Phenomenon That the Consensus Model Can't Explain
The student or teacher presents the learning community with an aspect of the anchoring phenomenon or a new, related phenomenon that is a problem for the students' current consensus model to explain. The role of the teacher in this element is to draw attention to and press the class to determine whether a particular key science idea (or sets of ideas) they developed could be pushed beyond what they had considered so far.

Element 2: Understand the Limits of the Model and Consider Ways to Revise It
See the "Element 2: Attempt to Make Sense" step of the Anchoring Phenomenon routine.

Element 3: Pose Questions to Resolve and Discuss Next Steps
See the "*Element 4: Pose Questions to Resolve and Discuss Next Steps*" step of the Anchoring Phenomenon routine.

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D. Driving Question Board

What is the Driving Question Board?
The Driving Question Board (DQB) is a tool used throughout the Open SciEd units as a way to generate, keep track of, and revisit student questions related to the anchoring phenomenon and related phenomena. Its use in OpenSciEd draws from work on project-based science learning, e.g., Singer, Marx, Krajcik, & Chambers (2000), Weizman, Shwartz, & Fortus (2010), and Nordine & Torres (2013). The Driving Question Board is a central support for the OpenSciEd Instructional Model.

The DQB is a visual representation of the class's shared mission of learning in the unit. The DQB is publicly displayed to serve as a learning resource for the community and should be easily accessible to students to see and add to during the unit. DQBs can be constructed with sticky notes or sentence strips; they can be written on whiteboards or with shared software applications (e.g., Padlet). Wherever and however they are constructed, it is essential that the board be available to all students throughout the unit.

When is the DQB used?
A DQB is introduced at the beginning of each unit in the Anchoring Phenomenon routine, and then revisited by the class as part of the Navigation, Putting Pieces Together, and Problematizing routines. The role of a DQB changes over the course of a unit. Initially the DQB enables the teacher and students to understand what students both know and do not know about the anchoring phenomenon. As the class revisits the DQB, students begin to answer questions on the DQB and can pose new questions.

How is the DQB used?
Students should understand that the DQB is not meant to set the agenda for the unit, but to serve as a record of students' curiosities about phenomena and a way of documenting the progress that they make in understanding the phenomena under study. It is important that students understand there will be more questions on the DQB than can be answered during the unit.

Ideas for preparing a DQB for the start of each unit follow:
- Use a large sheet of poster board or chart paper to make the DQB. At the top, write the unit question.
- Make a space in the classroom for the DQB that is easily accessible to students. Students will need to regularly go up to the DQB (over the course of the unit) to post their questions and look at the questions that their peers post. Ideally it is in a space where students can gather chairs around it and walk up to it to reach any part of it.
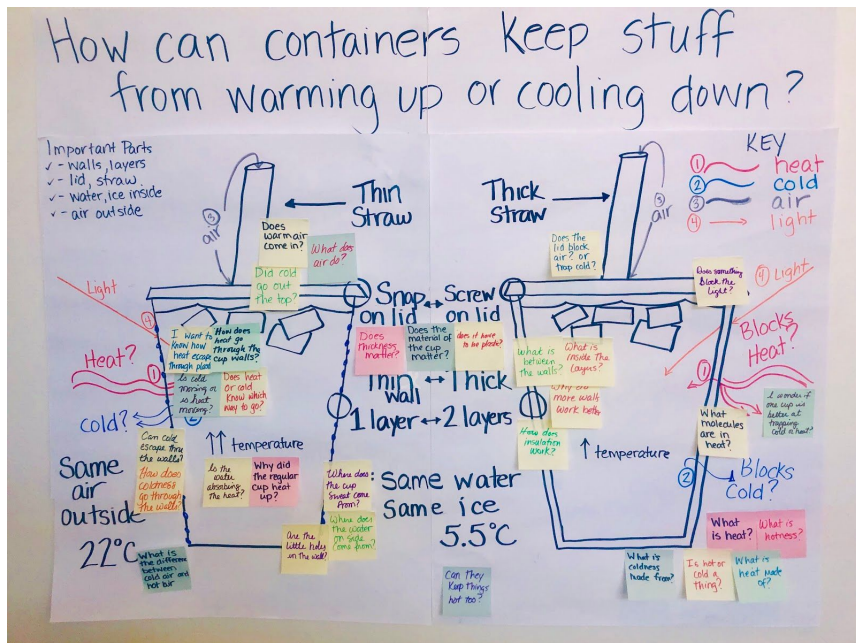
- Also create an Ideas for Investigations poster on chart paper to check off the ideas that the class pursues as it starts or finishes them. Add new ideas to the poster as students come up with them (additional pieces of chart paper may be needed.)

Additional examples of DQBs and Ideas for Investigation charts are shown below:

Portions of Section D were adapted from tools and processes developed by NextGen Science Storylines at Northwestern University and from the work of the Investigating and Questioning our World through Science and Technology Project at the University of Michigan, Northwestern University, and Michigan State University.

E. Developing and Using Science and Engineering Practices

The Science and Engineering Practices (SEPs) are intended to work together in a way to help students ask, investigate, and figure out science ideas. They represent the work that students do in the classroom. However, each unit cannot attend to all the elements of the SEPs; thus, each unit has identified specific science and engineering practices that will be the "focal" practices, or those in which the unit has emphasized the development or use of specific elements of that practice. Other SEPs are typically part of a unit, but the unit is not intentionally focused on developing that practice more fully and thus it is not called out as a focal practice. The focal practices are identified as part of the lesson-level performance expectations (LLPEs) and are discussed more fully in Section G (Assessment System).

If a practice is focal to the unit, additional instructional resources have been developed to attend to that SEP in particular. This might look like additional supports to develop and modify a model with scaffolded diagrams to support students, along with a student self-assessment rubric. Or, the support might look like sentence starters and self-assessment rubrics to support students in engaging in argument from evidence.

The following section includes specific supports for practices and will continue to be updated as more OpenSciEd units are released. Additionally, the OpenSciEd units include callout boxes for focal practices to help develop and use the practices within a lesson.

A Note about Developing and Using Models in OpenSciEd

What are models, and how can they be used?
A model is a representation of a phenomenon that is used as a tool to explain how or why something in the world works the way it does (NGSS Lead States, 2013; McNeill, Katsh-Singer, & Pelletier, 2015). In general, a model is defined by how it is used. For example, scientific models are sensemaking tools that help us predict and explain the world, while engineering models are used for analyzing, testing, and designing solutions (Passmore, Schwarz, & Mankowski, 2017). In general, models can be represented as diagrams, three-dimensional objects, mathematical representations, analogies, or computer simulations (NGSS Lead States, 2013). In OpenSciEd units, students build conceptual understanding of science by creating and revising models to explain phenomena. The course of a storyline can be described as a sequential process of developing and revising models to describe and explain different aspects of a phenomenon. Each section of a unit consists of an inquiry cycle with the goal of developing or improving a model of one aspect of a phenomenon. Students progress through the storyline by determining what aspects of the phenomenon they next need to explain. In addition to being the focus of students' work, models also serve as external representations of students' evolving understanding of the phenomenon.

Purpose
The purposes of engaging students in the development and use of models follow:
- **For students' own sensemaking:** Making visible students' ideas can help students consider the interrelationships between their ideas and consider non-visible components and processes that might be relevant for explaining the phenomenon.
- **To support students' work with others:** Representations can be useful for sharing their ideas with others to reach consensus.

- **To track progress in student learning over time:** Tracking the gradual development of ideas can help students individually and collectively make explicit what they've figured out, consider how their ideas are interrelated, and identify what is still needed.

How are models integrated into the OpenSciEd units?
The OpenSciEd units take a consistent approach to modeling so that students using these materials can develop and use models successfully within and across units. In each unit, teachers will see the following:

- In the Anchoring Phenomenon routine, students share their **initial model ideas** about the anchoring phenomenon and the causal mechanisms related to it. This might be a graphic organizer or chart of "What we think right now" or it could be an initial diagram of a system. This is typically done individually, but then shared as a class.
- Throughout the unit, students add their models ideas to a **Progress Tracker**. The Progress Tracker provides the space for students to document what they've figured out over time and consider what is needed to revise their models. At the same time, the class might use a *Gotta-Have-It Checklist*. This is a list of ideas that must be included in the final model.

At the end of the unit, students, both individually and as a class, develop a **final explanatory model** that can be used to explain the anchoring phenomenon and related phenomena.

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F. Developing and Using Crosscutting Concepts

OpenSciEd units support students to transition from highly scaffolded experiences with crosscutting concepts (CCCs) to limited scaffolding. The OpenSciEd materials can support this transition by providing explicit support for CCCs at moments early in an instructional sequence and removing those supports over time as students become more autonomous in their use of CCCs. Ultimately we want students to develop CCCs as strategies for reasoning about science that students can apply to a variety of phenomena–both in and out of school. To do this students must learn how to use these strategies through personal experience, discussion, and practice in developing scientific explanations. Below are a few examples of how our materials can support students in this process:

- *Support students' use of CCCs to ask productive questions about phenomena.* Students tend to struggle in their generation of productive questions. Students also get 'stuck' not knowing what kinds of questions they should ask. CCCs can be used by students to rethink a phenomenon and to identify productive kinds of questions they could ask about phenomena. Suggestions for how to use CCCs to help students generate productive questions are included in OpenSciEd teacher guides.

- *Provide principles and strategies to guide model-building and explanation.* The task of developing a model to explain a phenomenon can be daunting. The OpenSciEd teacher materials provide guidance on how students can apply one or two CCCs in their model building and explanation practice, cueing students to account for key elements they may otherwise miss. Prompts and checklists are provided in student materials to support them in applying these crosscutting concepts and reflecting on how they used them.

- *Sequence students' experiences of related phenomena in ways that engage students in analogical reasoning.* As students encounter new, but related phenomena, CCCs are a way to make sense of the new phenomena even if students are unfamiliar with science ideas necessary to explain the new phenomena completely. Thus, OpenSciEd units are strategic in sequencing students experiences of phenomena and encourage them to see similarities and differences between these phenomena (analogical reasoning).

OpenSciEd units have integrated instructional resources that use CCCs to scaffold student sense-making and discourse. One example includes integrating explicit question prompts to support the CCCs:

Example: Question prompts (STEM Teaching Tool #41, http://stemteachingtools.org/brief/41

Systems and Systems Models
- What are the key components of the system?
- Are there key components that are invisible?
- How are the components related?
- How do the parts of the system work together?
- What would happen in the system if you increased X component?

Structure and Function
- What unique structures does this object/living thing have?
- What function do the structures have?
- How does the structure facilitate the function?
- How does the shape of _____ help it function (or behave)?

Callouts to highlight crosscutting concepts

OpenSciEd callout boxes on the sidebar column are used to highlight CCCs where they are intended to be developed and/or used to help student sensemaking. In general, CCCs are particularly helpful in these key instructional moments:

- When we are stuck in generating questions and a CCC can help us focus our questions.
- When we are stuck in interpreting data and a CCC can give us a new way to look at the data.
- When we are setting boundaries/checklist/priorities for what to include in our models.
- When it makes sense to reflect on how a CCC was helpful to our thinking.
- When we are encountering a new, but related, phenomenon and we want to see how the new phenomenon is similar to or different from other phenomena we've explained.

The purpose of a CCC is to help move students forward through a science storyline (i.e., We are stuck, maybe thinking about _____ can give us some ideas of what's going on here.) CCCs should always be coupled with other dimensions and not taught as 'stand-alone' concepts. For example, when reflecting on the use of a CCC, it's important to emphasize how the CCC worked in tandem with a practice, or was critical for figuring out a Disciplinary Core Idea (DCI). Take advantage of pairings of CCC with DCIs or SEPs where possible, but look for 3D moments as well. Examples of some pairings include (not an exhaustive list):

- Systems and system models with modeling
- Patterns with data analysis
- Scale, proportion, quantity with mathematical/computational thinking
- Structure/function with engineering design and/or biological systems
- Cause and Effect with explanations

Portions of Section F are based on suggestions in STEM Teaching Tool #41 developed by the Institute for Science + Math Education at the University of Washington The full tool is available at http://stemteachingtools.org/brief/41

G. Assessment System

OpenSciEd has developed an assessment system that is grounded in the recommendations of the National Research Council (2014) report, *Developing Assessments for the Next Generation Science Standards.* An assessment system is a holistic way that supports teacher autonomy and multiple ways for students to demonstrate their ability to reason with the three dimensions. The system has assessments embedded in the unit, options for self- and peer-assessment, and multi-component tasks. The report recommended the use of multi-component tasks as a centerpiece for assessment, that is, tasks that are organized around a scenario presented to students that tests their ability to apply understandings of core ideas and crosscutting concepts to explain a phenomenon or solve a problem using science and engineering practices.

Types of Assessments

Each unit includes an assessment system that offers many opportunities for different types of assessments that work together to help teachers inform instruction throughout the lessons. The types of assessments that can be found are:

- **Pre-assessment:** Pre-assessment opportunities are found in early lessons in the units usually in the form of initial models and DQB questions. The goal of pre-assessments are: (1) to give teachers evidence for what ideas and practice competencies students are coming into the unit with and (2) to get a diverse set of ideas on the table that teachers can leverage throughout the unit to support argumentation and sensemaking. Many embedded instructional activities can be used as pre-assessments including initial models, driving questions for the DQB, and discussions around early class consensus models.
- **Formative assessment:** Formative assessments are meant to guide and advance learning through providing information that helps teachers learn about their students strengths and weaknesses and make subsequent instructional decisions. Formative assessment opportunities are built into the unit and meant to be points along the way where teachers can see where students are as they build understanding. In three-dimensional science instruction, this often means formative assessment happens as students are still working on building their understanding across the units and will often assess incomplete pieces of the final understanding. Look for formative assessment opportunities for each lesson performance expectation in the "Lesson-by-Lesson assessment" table.
- **Self assessment:** Self assessments are opportunities for students to learn and grow from their participation 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 self-assess their own progress by using more generic tools that help teachers facilitate student self-assessment. For example, the discussions rubric helps students understand and apply criteria for large and small group classroom communication.
- **Peer assessment**: There will be times in classrooms when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. OpenSciEd suggests that peer review happen at least two times per unit. The Peer Review Guidelines document (found in the Appendix) is designed to give options for how to support this type of assessment in classrooms. It also includes student-facing materials to

support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process.

- **Summative assessment:** Summative assessment opportunities are built into the unit and can occur at the end of each lesson set or the end of the unit. The purposes of summative assessment are to obtain evidence of what students have learned to 1) provide them with information on where they are in their learning (compared to where they need to be), and 2) provide teachers with information to adjust future instruction and usually assign a grade. Summative assessments can be transfer tasks where students are asked to make sense of a new phenomenon or they can be final models, arguments or explanations of the phenomenon explored in the class. Either way, summative assessments should be closely linked to the targeted performance expectations and directly address concepts and practices that the unit focuses on developing and using.

Each unit has identified these key moments of assessment and have included them, along with assessment and scoring guidance, in the Assessment Overview Table at the beginning of each Teacher Edition and within the keys and rubrics associated with lessons.

Formative Assessments and Lesson Level Performance Expectations (LLPEs)

A lesson-level performance expectation (LLPE) is a three-dimensional learning statement for each lesson aimed at highlighting the key student expectations for that lesson. Every OpenSciEd lesson includes one or more LLPEs. The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

Each unit includes a table that summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as *potential* formative assessments. Assessing every LLPE listed for each student can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion. However, the system is designed to support a quick review of the LLPE, assessment guidance, and a subset of student work to help inform instructional decisions throughout the unit even if you are not assessing each student individually every time.

Progress Trackers

The Progress Tracker is a formative and self-assessment tool that is designed to help students keep track of important discoveries that the class makes while investigating the phenomena, and to help them figure out how to prioritize and use those discoveries to focus on explaining the phenomenon they're working on. Students will refer back to the tracker regularly to revise or build on their models, explanations, and/or designs for their current thinking about the phenomenon. Furthermore, students, and the class as a whole, will use the tracker as a way to think with others about what is important in their models, explanations and/or designs.

It is important to note that this tool is designed to be a dynamic resource that students can use to progressively make sense of their ideas. OpenSciEd suggests that teachers use this tool to support progressive sensemaking throughout the unit, and avoid using this tool as a simple note-taking activity. In the teacher guidance for each lesson that use Progress Trackers, suggestions are given for supporting students in using the tracker in a way to identify discoveries and use those discoveries to continually revisit, revise, and prioritize ideas. In order to avoid Progress Tracker fatigue, teachers should not have students use the tracker every day in the same way, but rather, use it to further the sensemaking when applicable.

There are two structures that teachers can use during any OpenSciEd Unit. The choice provides teachers with flexibility to customize for their local context.

1. The two column Progress Tracker in a science notebook that includes only the "Question" and "What I figured out" columns.
   a. In the "What I figured out" column students can draw pictures or write in words, bullet points, whatever way is most meaningful for that individual. By having no structured box, students can take up a lot of space or a little space. Whenever a student is done, they can draw a line after their work to make space for the next time a teacher instructs them to write in their tracker.
   b. If a teacher decides that the class needs a break from using the tracker, the class simply doesn't fill it out and the next question would appear directly below (no blank rows would appear in the students' trackers).
2. The three column Progress Tracker that includes columns for "Question", "Source of Evidence", "What We Figured Out/Representation of Our Ideas"
   a. Students work on this row after important punchlines in the unit are figured out as a class, usually after the class came to consensus about an idea or set of ideas. However, it occurs more than only when the Putting the Pieces Together Routine is used.
   b. We do not suggest skipping this Progress Tracker move in the unit. If these pieces are missing, students may have trouble moving forward in their sensemaking.
   c. One place students can fill these out is during the "navigation routine" the next day after the class comes to consensus on something. This way it avoids the redundancy of coming to consensus and directly recording individually what the class figured out. It can also help reinforce using the Progress Tracker as a tool for formative and/or self-assessment.

Example of both forms of the Progress Tracker:

Our Driving Question: How does stuff inside our bodies make us feel the way we do?

Question	What I figured out
1. What's going on with M'Kenna's body that is making her feel the way she does?	Her symptoms seem to be coming from lot's of different parts of her body! Some of the symptoms started first and then others started to come later. I don't really know what's going on, but I have a lot of questions!
2. Can we see anything inside of M'Kenna that looks different?	MK's small intestine is really smooth compared to a healthy person's small intestine. Is her small intestine causing the problem?

Question	Source of evidence
3. Could food molecules be getting absorbed through the surface of the small intestine?	Dialysis bag experiment Molecular models of starch (big carbohydrate) vs sugar/glucose (small carbohydrate)
What we figured out in words/pictures	

> *Dialysis tubing is kind of like our small intestine - it's a big tube with holes*
>
> *When we put big food molecules like starch in the dialysis tubes they are too big to fit through the holes, but smaller food molecules like glucose can fit through. We knew this because the color changed on the outside -detecting the small food molecules, but not the big ones.*
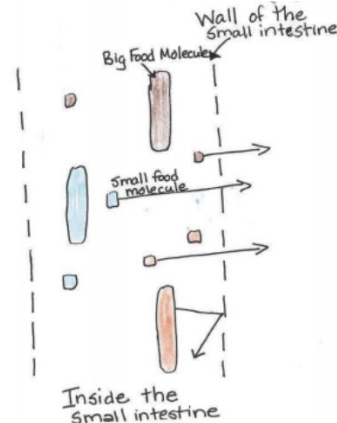
In the example trackers, each of the rows and columns has been completed with *possible* student ideas. This tracker serves as teacher guidance for what students may say at various points throughout the unit. Some students may say more and others may say less. It is important that what the students write in two column tracker reflects their own thinking at that particular moment in time. When the three-column tracker is filled out after a consensus moment in the unit, those rows will look more similar between students. In this way, the tracker can be used to formatively assess individual student progress throughout the unit, but also progress as a class. Because the tracker is meant to be a thinking tool for kids, we strongly suggest it not be collected for a summative "grade" other than for completion. This is to avoid undermining the freedom for students to put their current understanding and questions about their developing ideas without concern of being "right or wrong."

Assessment Rubrics

Assessments, along with guidance for their use, are included with each unit. However, there are general assessment rubrics that are integrated across more than one OpenSciEd unit. Examples currently include:

- Self-assessment for discussion
- Peer Feedback guidelines
- Modeling Rubric
- Argumentation Rubric

These resources are located in the Appendix, but are also found within each unit that uses them. The list of assessment rubrics will continue to evolve as more OpenSciEd units become available.

H. Classroom Culture and Norms

Purpose of norms

OpenSciEd materials rely on students collectively figuring out science ideas together through productive discourse and classroom talk. This requires a classroom culture where all students feel like they belong and it is safe to participate, share their ideas, disagree, and productively struggle together. Classrooms are learning spaces in which students' varied cultural and linguistic experiences and ways of knowing are an integral part of the learning community's sensemaking and can be leveraged to help develop and push all students' learning forward. The development and ongoing use of classroom norms can support safe and equitable student participation in collaborative sensemaking.

Norms to Support Productive and Equitable Participation

Respectful

In order for students to take the risk of making sense of complex ideas with their peers they need to feel safe and know that they will not be ridiculed or mocked. Establishing and enforcing norms that work to make the classroom a safe space to share is a prerequisite for productive talk. Providing each other with support and encouragement, sharing time to talk, and critiquing the ideas we are working with, but not the *people* we are working with are some norms that can support respect. Including students in conversations around establishing such classroom norms can be very helpful. For instance, have a conversation with students about what might prevent someone from participating in a discussion. Then brainstorm together agreements the class can make that might help **all** students feel comfortable sharing ideas. Explicitly addressing the idea that disagreements are an essential part of making sense in science, that these disagreements can sometimes feel like conflict, and then brainstorming ways that we can disagree with others' *ideas* is also essential. Additionally, working together to figure out reasonable and realistic consequences when someone says something disrespectful can help build the community norms and help students know what to expect as they continually work towards respectful discussions. These conversations can take place at the beginning of the school year, but also throughout the school year, to ensure that all students continue feeling supported and safe sharing their ideas in the classroom.

Equitable

If we value the importance of discourse in helping us figure out science ideas together, then *all* students need to have access to the conversation. This does not mean that every student has to talk during every discussion, however it should be clear that they are welcome and expected to participate. Discussions are not equitable if a few students dominate the conversation or if other students assume that certain students will carry the discussion. Norms to support equitable discussions include monitoring our own time spent talking, encouraging others' voices who we have not heard from yet, and recognizing and valuing that people think, share, and represent their ideas in different ways. Have a discussion with your students about ways to make sure that everyone feels welcome to join the conversation. When we engage students in academically productive talk, we are asking students to talk in ways they may not be comfortable with and would not be expected to talk at home. For students who are by nature very shy, for emerging multilingual students, for students with high-frequency learning needs, or for students new to academic discussions, scaffolding and support (both from the teacher and peers) may be required to help students formulate arguments and explanations in a way that others can hear, make sense of, and understand. One strategy to help students

who may be reluctant to participate is to ask them to simply repeat what someone else has said, in order to help clarify a classmate's idea. This strategy, along with revoicing an idea allows students to begin to be involved and allows others to hear the idea again so that they can work with it. Additionally, as students begin to see that these discussions are about making sense and thinking deeply, versus getting the right answer, they may feel more comfortable sharing.

Committed to our Community

We are working to "get smarter together". This means that WE learn together and it is not enough to just share our ideas without connecting to others' ideas. Establishing norms around being prepared and focused during discussions are important. Developing the idea that we all have a responsibility to our learning community to come prepared, share our thinking so that others can understand, and that we listen carefully and ask questions is important. Encouraging students to contribute ideas even when they are not sure and celebrating ideas (both correct and incorrect) goes a long way in supporting these norms.

Moving our Science Thinking Forward

We engage in these academically productive discussions in order to deepen our understanding and make sense of complex science ideas. Here we are talking about rigorous conversations where the focus is on using evidence and reasoning. Wrong or incomplete ideas are important resources and welcome opportunities to explore together as a community. Students will be asked to explain their thinking and say why they made a particular claim, regardless of whether their ideas are scientifically accurate or not. It is important to be aware that these types of questions traditionally signal to students that they are wrong. Consequently, it is important to establish norms around asking questions and working together to move our science thinking forward. We need to explicitly teach students how to use and build on others' ideas, the importance of providing and asking for evidence, encouraging others to clarify their reasoning, and being open to changing our minds based on new evidence. You can explain the kinds of talk moves you might use and then ask them how it makes them feel. For example, you might say, "I will ask you, 'why do you think that?'". If students indicate that such questions make them feel like they are wrong and not want to participate any further, you can explain and reinforce the importance of sharing their reasoning and how critical it is to help everyone learn. The more explicit we can be with the types of moves we (and they) can use to help move our science thinking forward, the more comfortable students can become.

Important questions to consider:
- Do you want students to participate in co-constructing classroom norms?
- Do you want the same set of norms for every section of science you teach?
- Do you want to work with your team teachers to establish a shared set of norms for students across all their classes?
- What kinds of consequences will you enforce if students do not follow the norms?
- How often will you check in with students about the norms and whether any need to be revisited or added to?

Strategies for developing community norms

When setting up community norms, students should understand how norms help everyone in the community understand what is expected of them. Two strategies for setting up norms include:

- **Give students a set of norms as a starting point**. Hand out a set of community norms at the start of the year. Have students discuss what the norms mean in their own words. Elicit from students the reasons these are good norms. Also, ask students which norms they feel might be challenging and why. Provide space for students to edit or add to the norms if students believe something is missing.
- **Co-construct norms with students.** Explain what norms are and why we need them for productive science talk and classroom culture. Have students co-construct norms, first sharing ideas in their small group, and then sharing out with the whole class. Compile a list of agreed-upon community norms. As the teacher, you can add norms that may be missing from the list. Make sure to explain to students how you think the norm you added is helpful, so that they are clear about why you are adding it to the list.

Tips for making norm-setting successful

- Every classroom community is unique and the norms for guiding behaviors in the community should fit the unique needs and experiences of the members. Consider the unique needs and experiences of your students and how much support they will need in establishing and following norms for productive talk in science.
- Make the classroom norms meaningful to the students you work with. A rigid list of "norms" given to students with no student input simply becomes a list of "classroom rules" and not a shared set of norms.
- Devote enough class time to co-constructing norms or discussing a set of norms. This will set clear expectations for everyone.

Strategies for actively using and reinforcing community norms

- **Help students understand rationale for norms**. In the first few weeks using the norms, when pushing students to practice specific discourse moves, ask students to reflect on why you're pushing them.
  - Why am I asking you to repeat what another student said?
  - Why am I asking for your reasoning?
  - Why is it okay to disagree with another student's ideas? How does doing so move everyone's science understanding forward?
- **Whole class check in**. Discussing progress with the norms regularly helps students understand that norms are expected behavior all the time, not just in the beginning of the school year, or when something has gone 'wrong'. Check in periodically with the class, asking students to reflect on:
  - How did we do today in our discussion?
  - What talk moves or norms do we feel we were successful with?
  - What talk moves or norms do we need to work on?
- **Partner check-in.** At the start of class have each student pick a norm they would like to focus on for the day and share that with a partner. At the end of the day, give partners time to share how they did with their focal norm. This elevates the community norms as students become more accountable for their actions, and helps students actively use and improve upon them.

A standard set of OpenSciEd Norms are found on the next page. These are provided with the first units of each grade level (based on the OpenSciEd Scope and Sequence), but serve only as a guide for classrooms. Additionally, the table on the next page provides example talk moves aligned to the norms.

Classroom Norms		Talk Moves to Support Norms
Respectful Our classroom is a safe space to share.	- We provide each other with support and encouragement. - We share our time to talk. We do this by giving others time to think and share. - We critique the *ideas* we are working with, but not the *people* we are working with.	"Daniel, that's a great idea. How do you think we could investigate it?" - Give time to think using wait time, turn and talk, or during individual writing time, such as Stop and Jot. "Why do you disagree with Juan's idea?" rather than "Why do you disagree with Juan?"
Equitable Everyone's participation and ideas are valuable.	- We monitor our own time spent talking. - We encourage others' voices who we have not heard from yet. - We recognize and value that people think, share, and represent their ideas in different ways.	"I'd like to hear from someone who hasn't yet gotten a chance to talk." "How did we do today in our discussion making space to hear from everyone?" "The way Shayna described _____ really helped me think about it in a different way."
Committed to our community We learn together.	- We come prepared to work toward a common goal. - We share our own thinking to help us all learn. - We listen carefully and ask questions to help us understand everyone's ideas. - We speak clearly and loud enough so everyone can hear.	"Who can paraphrase what Selma just said?" "What did your partner say?" "What questions do you have for Shereen about her idea?" "I think I heard what you said, but can you say it again to make sure everyone heard?"
Moving our science thinking forward We work together to figure things out.	- We use and build on other's ideas. - We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. - We are open to changing our minds. - We challenge ourselves to think in new ways.	"Why do you think that? What's your evidence?" "Do you agree or disagree with what Juan said? Why?" "Who can add onto Jerome's' idea?" "Did you see something represented in someone else's work that changes how you are thinking about _____?"

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I. Supporting Discussion

The communication of scientific ideas is a central part of the program's vision. In OpenSciEd, discussion is the glue that connects science and engineering practices to one another, and it connects those practices to disciplinary core ideas and cross-cutting concepts. Discussion is also the way that a classroom community makes sense of what it is investigating. Finally, discussion is the key to a classroom learning community in which all students' ideas are shared and valued. In OpenSciEd, we build upon prior work in the science education field on classroom discourse, productive talk, and support for discussion (e.g. Michaels & O'Connor, 2012; 2015; 2017) and tools developed by the Next Generation Science Exemplar Project (Michaels & Moon, 2016; Reiser, Michaels, Moon, et al., 2017). OpenSciEd units use specific types of discussions to help draw out student ideas, support students in communicating with one another in scientific ways, and support student sensemaking:

- Initial Ideas Discussions
- Building Understandings Discussions
- Consensus Discussions

Each type of discussion serves a different purpose, and is useful in different phases of a lesson or unit. Regardless of the type of discussion, it is always important to consider how to make it possible for all students to contribute ideas. Teachers are encouraged to set aside time for students to think individually and in small groups as part of a discussion plan.

Initial Ideas Discussions

Purpose
- To share students' initial ideas and experiences.
- To help students make connections between what they are learning in the classroom and what they have seen or experienced outside of school
- To provide a chance to share and make sense of ideas-even if those ideas are tentative or still being formed.

When This Type of Discussion Is Useful
- During the Anchoring Phenomenon routine
- During the Investigation routine
- During the Problematizing routine
- Any time students are beginning the process of making sense of a phenomenon

Strategies for This Type of Discussion
1. Provide a way for all students to surface their ideas (think-pair-share is one strategy).
2. Encourage students to use multimodal communication to express their thinking (such as gestures, graphical representations, etc.) and allow them to use all of their linguistic resources (this could include multiple languages).
3. Give students a chance to clarify one another's ideas and to ask about why students think their ideas are good ones.
4. Ask a student to summarize the class's initial ideas.
5. Ask students how they might test or further explore their ideas.

Building Understandings Discussions

Purpose
- To share, connect, critique, and build on others' findings, claims, evidence, and explanations.
- To provide the teacher and students with an opportunity to clarify which understandings emphasized in the storyline have been addressed and developed and which need further development

When This Type of Discussion Is Useful
- During the Navigation routine
- During the Investigation routine
- During the Putting the Pieces Together routine
- Any time students have been exploring new ideas.

Strategies for This Type of Discussion
1. Invite a student or group of students to share their current explanatory model or design solution with the class.
2. Invite others to ask questions about the model or solution, suggest additions to it, and critique the model or solution.
3. Invite a second student or group of students to share their model or solution, and then invite response and critique.
4. Ask students how the proposed models or solutions are similar and different.
5. Invite the class to consider what might need to be revised in the models or solutions, based on the models seen and the evidence which has thus far been gathered and made sense of.

Consensus Discussions

Purpose
- To collectively work towards a common (class-level) explanation or model. This includes capturing the areas of agreement for which we have evidence as well as areas where we still disagree and might need further evidence.
- Take stock of where we are in our figuring out and support the public revision of earlier ideas.

When This Type of Discussion Is Useful
- During the Putting Pieces Together routine
- Any time students have had the opportunity to construct new understandings.

Strategies for This Type of Discussion
1. Ask students to take stock of where the class has been and what it has figured out, offering conjectures or pieces of a model, explanation, or solution.
2. Ask students to offer proposals for a consensus model, explanation, or solution.
3. Ask students to support or challenge proposed models, explanations or solutions and to say what evidence is the basis for their support or critique.
4. Ask students to propose a modification to the model, explanation or solution based on input from the class.

Making Participation Equitable during Discussions

Discussions are a key point during instruction in which students' thinking, experiences, and ideas for further exploration can be surfaced and leveraged in the classroom. Below are some strategies for supporting equitable participation during discussions:

- In eliciting initial ideas or initial questions, the goal is to get as many ideas on the table as possible. Consider asking students to "write and pass" a sheet of paper around their group until they have at least 10 items. That way, all students get a chance to contribute, to see others' ideas, and to add their thinking in a low-stakes way. Make sure to let students know that these ideas can be expressed in different ways (e.g, pictures, graphs), and that they are not limited to words in English.

- Use student groups' feedback to prioritize ideas and questions for the class investigations. For example, have groups pass their written lists to another group, who circle the two "most pressing questions" on the list. As they do this, you can circulate and find the top four or five questions—this is your final student-generated list of driving questions.

- Think about what kinds of support your students might need to be able to ask each other to clarify and summarize questions without being critical or evaluative. You might try using the metaphor of a coach to introduce these think-pair-share routines. You could try telling students, "This is about helping your partners practice as a scientist and supporting them in their thinking, so you're going to ask questions about their ideas and encourage them to further develop their current understandings, and for now, your ideas will stay on the side line. Then we'll switch, and you'll get a chance to share your ideas as you are coached by your partners."

- Have sentence starters available for students so that they know what they might ask to push their partners further (e.g., "You mentioned_____, can you say more about that?), but also have sentence starters available to slow down the fast explainers (e.g., "Wait—you said that really fast. Can you say that again?")

- Consider a variety of ways for students to have these discussions, such as in a gallery walk where one person stays by the group's model, explanation, or solution, to invite and respond to critique, while other students ask pressing questions. During critique-based interactions, it is important to emphasize "making our ideas stronger," not "showing we have the best ideas" and that it is important to critique the idea, not the person. You can also encourage students to take a "coaching" stance here; their role is to ask questions that support others' ideas and to encourage other students to speak up when something needs to be clarified or repeated.

- Many students are not comfortable being the "only one" who voices a disagreement, a discontent, or a potentially wrong idea, so ask students to use the think-pair-share routine and to carefully listen to their partner's ideas. Then ask students to think about what they heard their partner saying, and ask the room if their partner's ideas are represented in the class discussion. This supports all students to share, to listen, to be heard, and for their ideas to be represented and used to further the classroom community's developing understandings.

Questioning Strategies to Support Discourse

To engage students in these types of discussions, OpenSciEd units suggest four questioning strategies for teachers to use to promote student discourse. These questioning strategies are intended to surface, challenge, and move forward student thinking while also fostering a community of science learners. While they are initially intended as questions that teachers can use, if they are incorporated as part of the norms of classroom culture, students will also begin asking these questions of each other.

These questioning strategies are (1) elicit questions, (2) probe or clarify questions, (3) challenge questions, and (4) support science discourse questions.

Elicit Questions
The goal of *eliciting* questions is to learn about students' prior knowledge and experiences, current understandings, and ways of making sense—whether their ideas are scientifically accurate or not. The more teachers understand how students are thinking about phenomena and science ideas, the better their instruction can be adapted to challenge misconceptions and to support the building of more scientific, evidence-based understandings. Elicit questions also help students see that different people have different ideas. Eliciting student ideas demonstrates to students that all ideas are valued. Student thinking becomes a resource (rather than an obstacle) that starts the process of making sense of new ideas. Students can construct new knowledge using their everyday ideas as stepping-stones toward deeper understanding.

Examples of elicit questions include:
- What are your ideas about (phenomenon)?
- What are your ideas about how to solve (this design challenge)?
- What experiences do you have that might help you think about (this phenomenon)?
- What are some ways we could test our initial thinking?
- What questions do we need to answer to solve the design challenge / explain the phenomenon?
- What are some of the key components of your model/solution?
- Could someone restate our question (or our charge)? What are we building consensus about?

Probe or Clarify Questions
The purpose of asking probing questions is to get more information about a student's thinking and understanding. It is not designed to teach new ideas or to "lead" students to a correct answer. Such questions can ask the student to give more information ("Can you tell me more?") or they can ask a student to clarify his or her thinking ("Did you mean . . . ?"). Like questions that elicit student ideas, questions that probe student thinking help you learn about students' prior knowledge, misconceptions, experiences, and ways of making sense. The more you can understand how students are thinking about science ideas and phenomena, the better you can adapt your instruction to challenge their misconceptions and to support them in changing their ideas toward more scientific, evidence-based understandings.

Examples of probe or clarify questions include:
- Can you say more about that?
- Where does that idea come from?
- Is that something you've heard, observed, or experienced before?

- What do you mean when you say the word "*X*"?
- Could you tell us more about that component of your model/solution?
- Can you clarify _____ aspect of your model/solution?
- Could you clarify the link you are making between your explanation and the evidence?

Challenge Questions

Questions that challenge student thinking are designed to push students to think further, to reconsider their thinking, to make a new connection, and/or to use new science vocabulary. Questions that challenge student thinking do not ask students to simply state a vocabulary term or definition, but rather ask them to use science ideas in a meaningful way. *Challenge* questions avoid leading directly to the right answer and focus instead on guiding student thinking toward a new concept or deeper understanding. The goal is to get students thinking more deeply while also scaffolding or guiding their thinking toward more scientific understandings.

Examples of challenge questions include :
- How does this model explain the evidence we have so far about this phenomenon?
- How does this solution fit the criteria we identified for a possible solution?
- Is there any evidence you know of that's not accounted for in your model/solution?
- How could we modify what we have, so that we account for the evidence we agree is important to consider?
- Is there more evidence or clarification needed before we can come to an agreement? What might that be?

Support Science Discourse Questions

Supporting science discourse in classrooms means engaging students in learning how to communicate effectively in the scientific community of the classroom, understanding the norms for presenting scientific arguments and evidence, and practicing productive social interactions with peers in the context of science investigations. Teachers can use and model questions with the purpose of explicitly supporting students in communicating in scientific ways with one another. Through these types of questions, students can be encouraged to listen to one another, consider each other's perspectives, and then decide how to best communicate their own thinking and evidence to peers. Explicitly reinforcing this type of communication to students is an important part of building a scientific community within the classroom where ideas are shared, challenged, refined, and built upon.

Examples of supporting science discourse questions include :
- Did anyone have a similar question to that?
- Does anyone have a different question that we haven't talked about yet?
- Can anyone add onto this idea?
- Who has a different way of thinking about this topic?
- Who can summarize some of the ideas we've heard today?
- Is this a complete summary? Can someone add what they think is missing?
- What questions do you have for this group about their model/solution?
- What do the rest of you think of that idea?
- Who feels like their idea is not quite represented here?
- Would anyone have put this point a different way?

Discussion Planning and Reflection Tool

Use this tool to intentionally plan for, facilitate, and reflect on key instructional moments in the classroom. It is not intended that this tool be used for every discussion; rather, choose one or two moments within a unit where discussion is particularly beneficial for advancing the storyline. Below are lists of questions for you to consider before, during and after the focal discussions:

Before the discussion:
1. What is the question students are trying to answer through this discussion?
2. What is the intended outcome of the discussion? (e.g., coming to consensus on something we just experienced? figuring out improvements to our model? designing an investigation? getting students to realize they have new questions?)
3. What are the key elements of the model or explanation you want the students to grapple with?
4. What other ideas might students have? What questions might they ask?
5. Where will you be going next and how will this influence how you wrap up the discussion? (e.g. problematize? continue investigation? design an investigation? apply ideas back to the anchor?)

Leading the Discussion
1. What will you say to launch the discussion?
2. What are some things you will say to encourage your students to work with one another's ideas?
3. If students seem to think they have explained the phenomenon but you know they need to go deeper, what kinds of questions could you ask to help students see the need to extend or revise their explanations?
4. What will you say to help close the discussion to establish a public record of what it is you all agree on and/or what new questions the class has?

After the discussion
1. What ideas and reasoning did you hear? How would you describe the groups' understanding of the ideas you identified in your planning?
2. What went well in the discussion?
3. What was challenging? Why do you think it was challenging?
4. Think about a moment when you weren't sure what to do. What *did* you do and why? And what was the result?
5. Is there anything you would do differently if you could do the discussion over?

J. Differentiation

There are many ways differentiation occurs in classroom settings. Teachers address their students' diverse learning needs in terms of student readiness, interest, and special learning needs and can make adjustments in terms of the content, the learning processes, and the student products that result from a learning experience (Tomlinson & Allan, 2000). OpenSciEd units were built with differentiation in mind, allowing teachers to adapt the materials as necessary without diminishing the learning experiences for students.

Differentiation of Content

Each OpenSciEd unit has been planned to target a bundle of Performance Expectations, as outlined in the OpenSciEd Scope and Sequence. However, the units may need to be taught in different orders for various reasons (e.g., to better align with a school district's scope and sequence) and/or individual students' understanding may be at, ahead of, or behind where they need to be for them to be successful in the unit. To support content differentiation, OpenSciEd units provide teachers with guidance on key ideas developed in the units. Additionally, each lesson includes information on "Where we are going" to help guide teachers on the key ideas for the lesson and prepare and support students as needed. Additionally, each unit provides information about mathematical standards that are necessary for students to fully engage in the unit's content and practices. This information allows teacher to make adjustments or provide students with additional supports if students are not mathematically ready for particular lessons in a unit.

An Example of Differentiation of Content
The One-Way Mirror unit is designed to be the first unit in the middle school OpenSciEd Scope and Sequence. As such, it explicitly connects to DCIs, SEPs, and CCCs from the grades 3-5 grade band to build on and reinforce ideas about light and how to represent the path light travels using a ray model. Many students might already be adept at using a ray model of light to represent their thinking, but if not, the unit includes a specific lesson (Lesson 3) that reinforces upper elementary ideas and practices for students. The unit provides guidance to teachers on how to modify the content if their students are more or less proficient than the intended lessons. The unit also explicitly integrates scaffolds for teachers as they support students transitioning from elementary to middle school level on the practice of Asking Questions and the concept of Systems and System Models. Teachers are provided guidance through the use of talk moves and rubrics, respectively, to support developing the elements of the practices and concepts at a middle school level.

Differentiation of Process

OpenSciEd units offer a variety of ways for students to make sense of the science ideas related to the phenomenon under investigation. The purpose of differentiating the learning process is to ensure that all students have access to the learning experiences and that they can fully represent their current thinking in ways that make sense to them, but can also contribute to the thinking of others. The units are designed in ways for teachers to flexibly apply grouping strategies and options for how students represent their thinking so that all students can participate and share their learning throughout the unit. OpenSciEd materials help teachers provide differentiation in the learning process by providing guidance on using different grouping strategies (partners, small groups, Scientists Circles) and/or different modes of representing thinking (e.g., individual Progress Trackers, Gallery Walk, using words and pictures to diagram their initial and revised models). Callouts within lessons provide teachers with guidance on adjusting the timing for students who may need more or less time to process the learning in the lesson.

OpenSciEd Classroom Norms also support differentiation of process. The norms are designed to reflect the various ways in which people communicate and represent their learning. Revisiting the norms frequently allows the class to focus on the different, and equally productive, ways in which their classmates are contributing to the shared work of the classroom.

An Example of Differentiation of Process
In the Cup Design unit, Lesson 4, guidance is provided to teachers in a callout box to modify the learning process to ensure all students are tracking the investigation's procedures:

> *Encouraging students to keep a record in their procedure by checkmarking each step they complete can help them develop a transferable approach to tracking their progress on any technical task in multistep procedure form. This can be particularly helpful for emergent multilingual students. You may want to emphasize that (1) following the steps carefully is more important than getting to the end of the procedure and (2) you want students to practice following a procedure and trust that as a whole class, we will be able to generate the data needed to analyze our results even if their group doesn't get to the last step. Reuse this approach in future labs when students have a multistep procedure to follow.*

Differentiation of Product

OpenSciEd units encourage teachers to be flexible with how students express their developing understandings and show their learning so that students have full access to demonstrate what they understand. There are many opportunities within the OpenSciEd units for teachers or students to choose the way they represent their thinking. This happens in almost every lesson with the use of a science notebook. The science notebook is the student's record of their thinking and allows for them to use words, pictures, and symbols in ways that help them make sense of the investigations and science ideas that emerge. The class often checks in as a group to develop a classroom consensus model, gotta-have-it checklist, or list of key principles, but during this consensus process, students negotiate with one another on how they are representing their thinking. Students are then able to revisit their own ideas in their notebook or handouts to revise their thinking and add ideas contributed by classmates. On assessments, students are asked to write or draw their current thinking, allowing students to show their learning in a variety of formats. This multimodal communication can be especially helpful for students with special needs, as well as for emerging multilingual students.

Example of Differentiation of Product
The assessment overview table in the One-Way Mirror unit provides teachers with guidance on how to use the students' initial models to gauge where their students are currently at the outset of the unit:

> *The student work in lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model of the two rooms is a good opportunity to pre-assess student understanding of light and matter.* **The ideas they represent in these notebooks reflects their current understanding of how to represent light, the direction light moves, and how light reflects off of or transmits through matter. It is important to not apply too many restrictions on students' initial models so that you can get a true picture of what students understand and then leverage that as they continually revise their models in this unit. All ideas and ways of representation are spaces to build on and ways for students to see other ideas in the classroom when they share models.** *As a pre-assessment, it is likely that students will mostly use*

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initial models to describe the video system and the box system and will only begin to use the models to explain how the system parts work together to cause the phenomenon. Look for agreement on key components of the system such as these:

- *two rooms or two sides in the system with the mirror/window between the sides*
- *one side is lit*
- *one side is dark*
- *on one side the person sees a reflection*
- *on one side the person sees through*

Where can Differentiation be found in the OpenSciEd Units?

OpenSciEd units specifically include differentiation strategies in the following sections of the units: Teacher background knowledge, the lesson-level "Where we are going" and "Where we are not going" sections, and the assessment overview and guidance tables. Teachers can find differentiation guidance within the Learning Plans in three particular types of callouts:

- Equity callouts focus on moments in instruction in which a certain population may benefit from a particular strategy, for example, supporting language development for emergent multilingual learners, providing extended learning opportunities or readings for students with high interest, providing specific strategies for students with special learning needs (e.g., using number or letter coded charts for students who are color blind as seen in the Cup Design unit, Lesson 1).
- Alternate Activity callouts provide guidance to teachers about going further or streamlining activities based on student progress and/or completing different learning activities. These can be particularly helpful for students with high interest or for students or classrooms that need to modify the unit based on availability of time or access to resources.
- Additional Guidance callouts provide more specific instructions to teachers about how to make a learning activity successful based on their students' needs. The callout boxes provide a variety of instructions to modify the timing, grouping, or resources for a particular activity.

Portions of Section J were developed with ideas from Tomlinson, C. A., & Allan, S. D. (2000). Leadership for differentiating schools and classrooms. Alexandria, VA: ASCD.

K. Attending to Equity

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. The units are designed to support learners who come from nondominant communities or from populations that are underrepresented in science, technology, engineering, and math (STEM) by offering students diverse entry points, experiences, and supports. OpenSciEd units use the following strategies to support equitable learning:

- **Focusing learning experiences on relevance to students and community purpose:** Units are designed to connect instruction to the interests, identities, and experiences of students and to the goals and needs of their communities. Strategies that have been used to achieve this goal include selecting phenomena that are interesting and accessible to a range of students and encouraging students to connect their experiences in class to their experiences in their homes and communities. For example, during the Anchoring Phenomenon routine in each unit, students identify related phenomena, which are then shared publicly to support and make visible these connections. This supports all students in being known and heard in the science classroom as their ideas are used to further the community's understandings.

- **Supporting equitable sensemaking:** The central role of collaborative sensemaking (or "figuring out") in the OpenSciEd units provides opportunities for students with diverse assets and perspectives to contribute meaningfully to the intellectual work of the classroom. Teachers should encourage students to express their ideas in language and discourse styles that they are comfortable with in order to open the conversation and sensemaking to all students. As described in section F, discussion and discourse are essential features of the OpenSciEd units. During the units, scientific language is developed as students experience science through the OpenSciEd routines. This language development occurs across multiple modalities, registers, and interactions providing different supports for a range of student learners.

- **Using culturally responsive and sustaining practices:** The OpenSciEd units value, make visible, and build on all students' ideas, including students from nondominant communities and populations that are underrepresented in STEM. Students' cultural and linguistic practices should be viewed as assets essential to the classroom community's efforts to make sense of natural phenomena, never as deficits or barriers to student learning. The role of the teacher is essential in this work as the teacher develops and fosters a classroom community in which students' ideas are shared and central to the storyline development of a unit.

- **Supporting an expansive view of learning through formative assessment:** Opportunities to assess student thinking are embedded throughout the units. These opportunities are designed to enable teachers to observe students' authentic reasoning and scientific ideas. At numerous points in a unit, students demonstrate their understandings of concepts and their abilities to employ science and engineering practices through a variety of performances that do not privilege particular cultural or language practices. Teachers can then use the information garnered from these formative assessments to adapt their instruction to better meet the needs and interests of all learners in their classrooms, and to more meaningfully connect to their students' lives.

Each unit was designed using these strategies, which are integrated throughout the OpenSciEd routines. In order to highlight the rationale behind these choices as well as to provide teachers with guidance on how to adapt the materials for their students, these strategies are discussed in the teacher guide in educative boxes titled "Attending to Equity." These educative boxes are embedded within the lessons in each unit to provide specific and just-in-time support for teachers. For example, in relation to the use of sentence starters in the student notebooks, an "Attending to Equity" box states: "Using sentence starters in science notebooks supports students in developing their ability to communicate in scientific ways. Sentence starters are particularly helpful for emergent multilingual students." Additional supports for equity will be added to the units and this handbook in 2019-2020.

L. Supporting English Language Arts (ELA)

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

Use of Text

The units 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. 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. 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, an abstract and methodology section from a study, or field observations). Some text is just-in-time to help the storyline along, to generate questions or ideas from students, to help to clarify some piece of the puzzle students are figuring out, or to give students language to describe what they are seeing. Texts are also used to extend learning or satisfy student curiosity related to the phenomenon. Current and future texts will feature people of different ages, genders, cultures, abilities, and racial and ethnic groups engaged in the scientific enterprise, and include individuals with different perspectives, working toward similar or different purposes, as part of different disciplines and communities (such as citizen scientists, families, or classmates).

Students analyze texts using strategies drawn from *Common Core State Standards*, and these connections are outlined at the end of each OpenSciEd lesson. Lessons are designed to have students cite specific textual evidence to support analysis of science and technical texts; determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions; follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context; analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic; analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text; integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (such as a flowchart, diagram, model, graph, or table); distinguish among facts, reasoned judgment based on research findings, and speculation in a text; and compare and contrast the information gained from experiments, simulations, videos, or multimedia sources with that gained from reading a text on the same topic.

The OpenSciEd units include several strategies for text analysis. One strategy, a **close reading strategy,** is used throughout the units as a common approach for students to engage with text. The steps in the strategy include:

1. Identify the question(s) you are trying to answer in the reading.
2. Read once for understanding to see what the reading is about.
3. Read a second time to highlight a few key ideas that help answer the questions you had.
4. Summarize the key idea(s) in your own words, in diagrams, or both.
5. Jot down new questions that this raises for you.

Example directions found in the Learning Plan of a lesson:
Model the close reading strategies. Project **slide C**. Describe that close reading requires reading more than once and with different purposes and strategies for interacting with the text. Go through the following steps, which are on the slides, with students:

1. Project **slide D**. Say, "Let's do one together. Ask students what the main question in this reading is that we are trying to answer. Tell students to circle the *What is Air?* question at the top as a key strategy because it reminds us what the purpose is of what we are trying to do and the type of information we are looking for in the reading.
   Have students write down this question at the top of the reading: **What is in the air?**
2. Project **slide E**. Give students time to read the first two paragraphs of the reading on their own.
3. Project **slide F**. Show students an example of step 3 by rereading aloud the first section. As you read, pause and share your thinking, highlighting a few ideas that answer our focus question.
4. Project **slide G**. Tell students they are going to try steps 4 and 5 by adding the summary of key ideas and new questions they have to their Progress Trackers. Project **slide H**. Tell students to fill in a row of their Progress Trackers with what they just figured out.

Emphasis on Communication

Students are frequently engaged in speaking, listening, and responding to others as part of their participation in scientific and engineering practices. The units provide guidance and rubrics aligned to *Common Core State Standards* for speaking and listening, including standards for comprehension and collaboration, and presentation of knowledge and ideas. Students frequently engage in peer-to-peer discussion to share, express, and refine their thinking based on new information. They develop, present, and defend their ideas to one another, verbally, in written forms, and in expressive forms in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details. See appendix for resources on discussion and peer feedback.

Writing in Science

OpenSciEd units 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. Written work integrates standards for writing from the *Common Core State Standards*, and instructional materials ask students to articulate claims and arguments, cite evidence from their own work and scientific sources, and evaluate the claims and

counterclaims of others. Students draw upon a variety of texts and analyze graphs, tables, and images as part of writing development. These connections are noted at the end of each lesson.

Science Notebook Management

Purpose of the Science Notebook
The science notebook creates a space for students to record investigations and communicate their ideas about phenomena. The notebook is also a record of how students' ideas evolve over time. Developing a science notebook can create a sense of ownership from students with respect to their intellectual work in the classroom. It can also be a valuable formative assessment tool for teachers.

Tips for Setting Up the Notebook and Organizing the Work
What type of notebook should we use? Composition notebooks are inexpensive and easy for classroom and backpack storage. The downside of using composition notebooks is the reduced page size, where students may run out of room as they record their work. Spiral notebooks afford more space on the page but can be problematic for storage. Either is fine for use as a science notebook in your classroom. Handouts can be taped or glued into the science notebook, and they may be folded in half to fit on the page.

How can I help students organize their notebooks? The level of organization you want students to use with science notebooks will depend on your teaching style and the goals for notebook use in your classroom. The organization can range from highly structured and sequential to random. If the notebooks are too random, students may struggle to locate their work and to track their developing understandings. Some organization, particularly early in students' use of the science notebook, can be useful so that students develop a vision for what to record and how to record it:

- **Page Numbers:** One suggestion for organization is to use page numbers. Have students number the pages at the start of the year or the start of a unit (e.g., the first 50 pages or so). Then ask students to record their work on a specific page number that the whole

class can reference at a later date (e.g., "Let's look at the model we drew for *X* on page 35.").

- **Table of Contents:** Another organizational tool is a table of contents. This can give students flexibility to record their own page numbers that correspond with different activities. If you choose to use a table of contents, make sure to offer time at the end of class for students to update their tables of contents.

What do students include in a notebook entry? Students should title the notebook entry for easy reference later. Additionally, students can write the lesson or investigation question near the top of the page to remind them of the purpose of the investigation and what they are trying to figure out. Students may also date their work.

Tips for Using the Notebook Effectively

What is recorded in a science notebook? Anything can be recorded in the science notebook, but you will see the following kinds of activities used throughout this curriculum:

- Recording student thinking (e.g., Notice and Wonder charts, initial ideas and questions, explanations)
- Recording models (e.g., individual models and the Model Tracker)
- Recording investigations and analyses (e.g., data tables, observations, technical drawings of a lab, graph analysis)
- Readings, short notes, and vocabulary (e.g., glossary, short readings marked up with students' analyses, brief notes on a science idea)

To Record Student Thinking: Students are prompted to communicate their thinking throughout the curriculum. Sometimes students complete a quick *stop and jot*. Other times students might be prompted to write an explanation of a phenomenon. And other times, students work in groups to record their ideas in response to discussion prompts. A Notice and Wonder chart (shown on the previous page) is one example that shows what students are attending to during an investigation and the questions they have. All these activities offer a window into students' ideas and how they are developing across the unit.

To Record Student Models: Students record individual diagrammatic models and their Model Trackers in their notebooks. These are particularly valuable representations of student thinking that demonstrate how students' knowledge evolves over the course of the unit. Students' models and the Model Tracker may use handouts taped or glued into the notebook, or they can be drawn in directly. Handouts for modeling activities provide scaffolds for the model and can save instructional time.

To Record Investigations and Analyses: Students can use their notebooks to make observations of phenomena and to record and/or analyze data. Students may draw data tables and graphs directly into their notebooks, or tape or glue a handout into the notebook.

Time is an important factor to consider when deciding whether to ask students to hand-draw directly in the notebook or to tape in a handout. The goal is for students to spend most of their time in deep analysis and sensemaking around their observations, and not in the construction of the data table or graph. The data table below on the left is an example of an easy table for students to draw without consuming instructional time. The graph below to the right is more time intensive for students to develop, but it may be worthwhile if students are engaging in deep thinking around producing the graph. For example, in this particular activity

students recorded their observed data (blue circles) and worked together to estimate the percent illumination on days between their observed data.
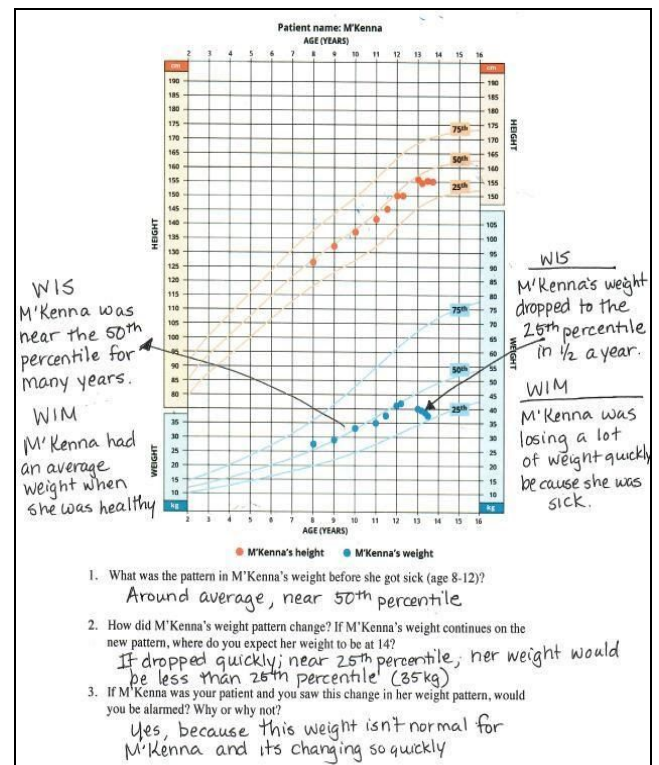
Example of hand-drawn data table:

Example of a handout graph taped or glued into the notebook:

Developing Scientific Language

Some instructional approaches emphasize the role of introducing key vocabulary before learning about the concepts they are connected to in a lesson. That is *not* an approach we support in OpenSciEd units. While we agree that developing scientific terminology is one important goal for students, it should not undermine the heavy lifting we want students to engage in intellectually. In each lesson we want students engaging in practices around a question that they feel a genuine need or drive to figure out. Front-loading vocabulary hinders this process and also puts up barriers on emergent multilingual students to engage in class discussions.

Students can communicate about and grapple with phenomena without using scientific terms. Once ALL students have developed a conceptual understanding of an idea in a lesson, introducing a relevant scientific term as a shorthand way to reference that idea makes complete sense. It is simply a matter of timing and where we want them focusing their intellectual work.

Here is an example: In a unit on sound, students notice that the graph of the vibrations produced by an object exhibits two interesting characteristics. A few rounds of trying to describe patterns (first individually, then with a partner, and finally as a whole group) leads students to start talking about two features of these patterns that can be compared and measured. One feature can be described in terms of the distance from

the *y*-value of a high point on the graph. The other can be described in terms how often that pattern repeats. It is at this point, after the class has worked with these ideas for a bit and wrestled with what words best describe each feature, that the teacher can point out that it seems cumbersome to keep referring to these features to describe the graphs, and that two terms are used to refer to these features. One is *amplitude* and one is *frequency*. At this point, it makes sense to consolidate students' ideas by showing how these two terms correspond to the patterns they observed and were describing. From this point on, using these terms to represent these features of such graphs is meaningful and appropriate.

This approach to vocabulary building doesn't undermine the sensemaking of students, nor defeat the goal of figuring out important science ideas in each lesson. We want to give students a rich opportunity and experience to wrestle with developing these important science ideas before introducing vocabulary to represent an abbreviated description of those ideas.

As new scientific terminology is developed with the class, we recommend that you build a word wall (example shown above) of these ideas. Keeping a visual model, or examples if applicable, next to each word can help students recall the concept the word is associated with.

M. Supporting Mathematics

The goal of integrating mathematics within units is to use mathematical understanding and practices to develop and reinforce important science ideas and practices, while supporting students in strengthening their math understanding and practices, and demonstrating the importance of mathematical thinking and practices to science.

The OpenSciEd units are intentional in their placement and purpose of mathematics. Mathematics is intended to help the storyline along, to help to clarify some piece of the puzzle students are figuring out, or to give students tools to highlight, analyze, and interpret important patterns in the data they are exploring. When applying mathematics, materials connect to and reinforce the *Common Core State Standards for Mathematics*. Mathematical analysis is not be used in isolation of developing understanding of the target science ideas. Connections to mathematics are noted at the end of each lesson where appropriate.

The OpenSciEd units integrate mathematical understanding and practices that are grade-level appropriate across both math and science standards. They align to the development of the mathematical topics in the *Common Core State Standards for Mathematics,* and do not require or attempt to teach them before they have been addressed in the *Common Core*. For example, statistical measures of center are not introduced until Grade 6 and probability is not addressed until Grade 7. Guidance on mathematical knowledge and practices is provided in the Teacher Background Knowledge for each unit to indicate alignment to the *Common Core* and to alert teachers for opportunities to attend to the connections.

Where appropriate, the units provide support and modifications for students with special learning needs related to mathematics. For example, they may provide alternate students prompts to provide opportunities for students to engage with the mathematics qualitatively rather than 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. Where possible, teacher materials provide support to break down analysis of the data into smaller steps or explain the problem in a different way.

Appendix

Self-evaluation: Engaging In Classroom Discourse

Setting	Criteria	Absent I do not do this	Developing I occasionally do this (sometimes)	Proficient I often do this	Mastery I consistently do this
In large/whole group settings (Scientist circle discussions, gallery walks, etc…)	**Shares one's own thinking** by contributing new ideas, questions, and additional clarification.				
	Listens actively to others, rephrasing, repeating and/or reusing the ideas others have shared and asking others to repeat their statements or to clarify ideas when they are difficult to hear or understand.				
	Respectfully provides and receives critiques about explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions.				
	Invites others to share their thinking and contribute their ideas.				
Setting	Criteria	Absent I do not do this	Developing I occasionally do this (sometimes)	Proficient I often do this	Mastery I consistently do this
In small group settings (partner talk, small group discussions, lab work)	**Shares one's own thinking** by contributing new ideas, questions, and additional clarification.				
	Listens actively to others, rephrasing, repeating and/or reusing the ideas others have shared and asking others to repeat their statements or to clarify ideas when they are difficult to hear or understand.				
	Respectfully provides and receives critiques about explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions.				
	Invites others to share their thinking and contribute their ideas.				

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Peer Feedback Facilitation: A Guide

with Student Guidelines and Rubrics

Teacher Instructions

There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happen at least once, but preferably two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process.

When is a good time to facilitate peer review?
Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving the peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback.

What are classroom structures I can use for peer review?
Below are three examples of ways to organize peer review in your classroom. You may choose to use all of them depending on your time or material constraints or you may choose to always use one structure for review so that your students get familiar with it and better at it over time.

Sticky Note Peer Review: In this protocol – shared on *Tools for Ambitious Science Teaching* – students use sticky notes to leave questions and comments on posted student work. There is time built in for students to respond on feedback. Use the self-assessment rubrics in this document at the end of the class period for students to reflect on their experience in this feedback session.

Peer Review with Unit Rubrics: Each unit and the OpenSciEd curriculum overall have Science and Engineering Practice (SEP) specific rubrics for teachers to assess student work. You can also use these as a way for students to assess each other's work and give feedback on how to improve. For example, in the Sound unit during lesson set one students develop models of how objects vibrate to make sound. They can be assessed with this rubric. We suggest having students use the rubric to give specific feedback to each other. You can use this in a gallery walk type setting or have students exchange models.

Group Review: Ask students to get into groups of four. Have the students bring their individual model or explanation (or other piece of student work to the group). Review feedback guidelines as a class giving examples of good and bad feedback. Then, in pairs, have students provide feedback to the other two pieces of student work. They can use sticky notes or write directly on the work. Make sure to leave individual work time for students to revise their models and complete the self-assessment rubric.

Giving Feedback to Peers

Feedback needs to be specific and actionable.

That means it needs to be related to science ideas and provide your own suggestion for improvement.

Productive examples:

- "Your model shows that the sound sources changes position when it is hit. I think you should add detail about how the sound source moves back and forth after it is hit."
- "You said that the drum moves when it makes sound but the table doesn't move when it makes sound. We disagree and suggest reviewing the observation data from the laser investigation."

Nonproductive examples of feedback that do not help other students improve are:

- "I like your drawing."
- "Your poster is really pretty."
- "I agree with everything you said."

How to Give Feedback:

Your feedback should give ideas for specific changes or additions the person or group can make. Use the sentence starters below if you need help writing feedback.

- The poster said _____. We disagree because _____. We think you should change _____.
- I like how you _____. It would be more complete if you added _____.
- We agree that _____. We think you should add more evidence from the _____ investigation.
- We agree/disagree with your claim that _____. However we do not think the _____ (evidence) you used matches your claim.

Receiving Feedback from Peers

The purpose of feedback is to get ideas from your peers about things you might improve or change to make your work more clear, more accurate, or better supported by evidence you have collected or to communicate your ideas more effectively to others.

When you receive feedback, you should:

- Read it carefully, ask someone else to help you understand it, if needed.
- Decide if you agree or disagree with the feedback and say why you agree or disagree.
- Revise your work to address the feedback.

Self Assessment: Giving Feedback

How well did you give feedback today?

Today, I…	YES	NO
Gave feedback that was **specific** and about **science ideas.**		
Shared a suggestion to help improve my peer's work.		
Used evidence from investigations, observations, activities, or readings to support the feedback or suggestions I gave.		

One thing I can do better next time when I give feedback is:

Self Assessment: Receiving Feedback

How well did you receive feedback today?

Today, I…	YES	NO
Read the feedback I received carefully		
Asked follow up questions to better understand the feedback I received		
Said or wrote why I agreed or disagreed with the feedback		
Revised my work based on the feedback		

What is one piece of feedback you received?

_____

What did you add or change to address this feedback?

_____

Example Modeling Rubric from *Sound*

Component Clearly represents or describes the system components and must include:	Category			Feedback
	Missing	Developing	Mastered	
● the **sound source**.				
● the **initial force applied** to the sound source.				
● the **particles of the medium** (air) in between the sound source and detector.				
● the **detector** of the sound.				
Interactions Between Components Clearly represents or describes the following:	Category			Feedback
	Missing	Developing	Mastered	
● the deformation of the sound source causes the particles in the medium to start moving *(cause/effect)*.				
● that particles in the medium go back and forth and hit neighbors (show this with some sort of convention for wiggle) *(cause/effect)*, but do not move all the way from the source to the detector.				
● the repeated nature of this back and forth motion of the shape of the sound source (may identify this back and forth motion as a vibration) *(pattern/structure)*.				
● that the particles of the medium push on the "detector", causing it to move *(cause/effect)*.				
● that collisions transfer energy across the medium (the energy moves from the sound source to the detector, but the particles do not move all the way from the sound source to the detector) *(energy)*.				
● that particles and the sound source go back to their original starting position *(pattern/structure)*.				

Argument Rubric from *Inside Our Bodies*

Claim	Category			Feedback
	Missing	Developing	Mastered	
● **There is a claim** that states that M'Kenna has Celiac Disease.				

Justification **Evidence or empirical data** that supports the claim includes:	Category			Feedback
	Missing	Developing	Mastered	
● M'Kenna's endoscopy images of her small intestine look differently than the healthy small intestine images				
● Graphs show that M'Kenna is breaking down all large food molecules except for all "other complex carbohydrates"				
● Graphs show M'Kenna has food molecules left in her large intestine and poop, that are not found in a healthy person				
● M'Kenna has flat villi in her small intestine				
Scientific principles or ideas that explain how each piece of evidence supports the claim (*reasoning*) includes:				
● Since there are structural differences in the small intestine images, this indicates there could be a difference of M'Kenna's function of her small intestine				
● Since small molecules are not being absorbed by the small intestine, they continue moving down her digestive tract and end up in her poop				
● The food molecules are being broken down in M'Kenna and in a healthy person because we see large food molecules in the graphs go down and small food molecules go up, but then in M'Kenna they all are not being absorbed because food molecules are still left in her poop and large intestine				
● Flat villi make it more difficult to absorb food so small molecules are left over in the process as food moves through the body. The villi are the cells of the digestive system in the small intestine where food is absorbed. When functioning properly, villi increasing the surface area in the small intestine where small food molecules can be absorbed (*structure/function*)				

Rebuttal Clearly represents or describes the following:	Category			Feedback
	Missing	Developing	Mastered	

● a critique of the evidence of an alternate claim
  ○ Not other diseases because the damage located in the small intestine
  ○ The other small intestine diseases are not caused by damage to the villi structures
  ○ Any other valid critique that relies on evidence				

● a critique of the reasoning of an alternate claim
  ○ The disease M'Kenna has must be related to the small intestine because that is where we knew there was damage from the images we examined
  ○ The disease M'Kenna has must be a result of or related to the damage of villi in the small intestine because we know that the damage villi absorb small molecules less efficiently than normal villi which can explain why we see small molecules in M'Kenna's poop.
  ○ Any other valid critique of reasoning that students propose				

Acknowledgments

This handbook represents a synthesis of ideas, strategies, and resources developed across the science education community. These resources include:

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