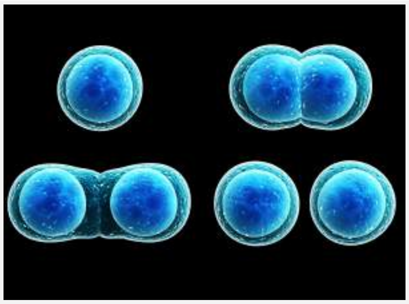
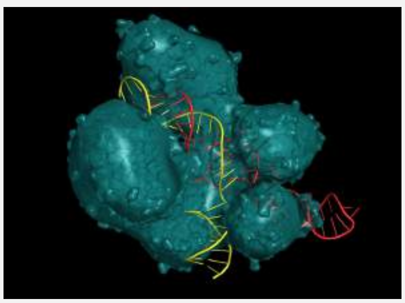
inquiryHub Biology

A 3-Dimensional High School Biology Curriculum





The inquiryHub (iHub) biology curriculum is a full-year high school biology course anchored in phenomena and aligned to the Next Generation Science Standards.

Denver Public Schools teachers, working with a team of researchers from the University of Colorado Boulder and Northwestern University, designed three units, which address all of the performance expectations in the NGSS for high school biology. Scientists are part of the team and have reviewed all content for accuracy. Achieve, Inc., which reviews science units, has reviewed the first unit in the curriculum and rated it as High Quality NGSS Design if Improved.

The units are organized around coherent storylines, in which students ask and investigate questions related to an anchoring phenomenon or design challenge. Students use science and engineering practices to figure out Disciplinary Core Ideas (DCI) and crosscutting concepts needed to make sense of and explain the phenomena or solve the problem presented in the challenge.

The phenomena that students work together to explain in biology are antibiotic resistance and a bird population that evolved to become bold (Evolution), Duchenne Muscular dystrophy and gene editing (Genetics), how trees can mitigate climate change and population changes among large animals on the Serengeti (Ecosystems). Each has been chosen with input from Denver students as to what would be interesting and engaging to students like them.

Students engage with all eight science and engineering practices, becoming more proficient in learning when and how to use the practices. Lessons engage students in practices where they investigate, make sense of phenomena and problems, construct and critique models, and develop explanations and arguments. The units are designed to support students in becoming more sophisticated in their use of practices over the school year. Design challenges help students integrate knowledge across units; over time, students are expected to take more and more responsibility in problem solving within them. At the end of the genetics unit, students organize a World Cafe where they design questions for and facilitate a dialogue with peers, parents, and community members about the ethics of genetic engineering.

There are multiple assessments embedded in the materials that can be used for formative and summative purposes. These include exit tickets with multiple-choice questions that assess both student experience and understanding, student models of phenomena, and 3D transfer tasks in which students apply what they have learned to a new phenomenon. The modeling tasks are accompanied by SLO rubrics that can be used to build a portfolio of evidence of student progress.

These materials were developed by the inquiryHub RPP, including educators from CO and IL, Northwestern University and the University of Colorado Boulder, with support from the National Science Foundation, the Gordon and Betty Moore Foundation and Denver Public Schools.

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Unit 1 Evolution: Why don't antibiotics work like they used to?

Timing: 10 weeks (50 50-minute class periods)

Anchoring Phenomenon: Addie, a girl, who gets sick from antibiotic resistant bacteria (Bend 1) and the rapid evolution of behavioral and physical characteristics of dark-eyed juncos in San Diego (Bend 2).

Description: This high school unit on natural selection and evolution starts out with students exploring the case of a young girl with a life-threatening infection of pan-resistant bacteria. This case sparks questions that lead them to investigate the growing prevalence of similar cases and the discrepancies between antibiotic use in their communities and CDC recommendations. This can motivate students to take on an optional citizen science mission to figure out why this is happening to help develop infographics to sway individual health choices related to the (mis)use of antibiotics.

Students use the model they developed (of natural selection) to return to the anchoring phenomenon of Addie that launched the unit, to explain the growing prevalence of antibiotic resistant bacteria in hospitals and their communities over time. Students then identify criteria for a model organism, in an effort to determine the extensibility of their model's ability to explain other types of changes occuring in other populations, other than bacteria. The case they explore next is a group of juncos that have changed rapidly over the past 60 years. One population of these birds that has made its home on the UCSD campus exhibits bold behaviors and unique physical traits that distinguish it from its mountain cousins. This phenomenon sparks questions about whether these differences in behavior are learned or inherited, what led to differences in mating and migration patterns, and what led to the different physical trait variations.

Students culminate their work in this storyline, arguing that their model of evolution applies to all life on Earth, including bacteria and humans, and they investigate how environmental changes over deep time have contributed to the emergence of new species and the extinction of others.

Performance Expectations:

HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

HS-LS4-6: Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

HS-LS2-8: Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.

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HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Unit 2 Genetics and Heredity: How can science be used to make our lives better?

Timing: 6 weeks or 28 50-minute class periods

Anchoring Phenomenon: the symptoms and progression of Duchenne Muscular Dystrophy (Bend 1) and use of the CRISPR-Cas9 protein system as a tool for editing genes (Bend 2).

Description: This high school unit on genetics starts out with students making observations and posing questions about what they see in a brief video that depicts boys who have Duchenne Muscular Dystrophy (DMD). The video depicts them in their everyday lives, enjoying the company of others, but needing support to move and, in some instances, to breathe. Students begin by investigating how muscles work and how they function differently in boys with and without DMD. They investigate the function of the protein dystrophin in healthy muscle functioning and how the protein is produced in healthy individuals and about the role that a heritable genetic mutation plays in inhibiting the production of dystrophin in boys with DMD. Students explore different ways that heritable diseases are passed down to develop an explanation for why only boys manifest the disease.

Students use what they have learned about the role of DNA in heritable diseases to investigate an emerging gene editing technology, a system called CRISPR-Cas9, a bacterial defense system that scientists have discovered how to use for different purposes. Students evaluate evidence about the use of CRISPR-Cas9 to cure diseases in mice, including muscular dystrophy. Students build a model showing the conditions under which the system could be used to cure diseases in humans.

The unit culminates with students designing a World Cafe event with students in their classroom that is implemented district-wide. In the World Cafe, students pose and debate questions related to the ethics of emerging genetic engineering tools like CRISPR-Cas9.

Performance Expectations:

HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

HS-LS3-2: Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Unit 3 Ecosystems: How do small changes make big impacts on ecosystems?

Timing: 8 weeks (40 50-minute class periods)

Anchoring Phenomenon: The population of large herbivores on the Serengeti plain has been changing rapidly since 1960, marked by a rapid increase of herbivores (buffaloes and wildebeests) and then a rapid decline of the buffaloes. This population change caused by disease elimination has entirely changed the Serengeti ecosystem in a relatively short period of time (Bend 1). Trees are able to sequester carbon from the atmosphere and tree planting is one way scientists have proposed to mitigate the effects of climate change (Bend 2).

Description: Bend 1 unit begins with students posing questions to investigate related to the rapid increase and decline of the buffalo population in the Serengeti. Students develop initial hypotheses of what could have happened, from an increase or decrease in predators to drought to warfare. They develop a plan to investigate each of their hypotheses and explore data related to predator-prey relations, migrations, climate, human impacts, and disease. Students figure out that a cattle disease called rinderpest artificially kept the buffalo population low until 1960 and also kept the wildebeest population low. The increase in the wildebeest population, which migrates across the Serengeti seasonally, led to several changes in the ecosystem: greater fire suppression, which led to the growth of more trees, which led to an increase in the giraffe population that fed on the new tree growth. Students explore and manipulate a simulation that helps them put together their ideas about the ecosystem dynamics to construct an explanation for what happened to the buffalo. They then apply and revise that model in light of new evidence to explain what happened to the ecosystem during the period when the population of buffalo declined. The bend culminates with students evaluating the claim that the wildebeest function as a keystone species within the ecosystem that has a strong influence on ecosystem dynamics.

Bend 2 starts out with students posing questions about a video that presents claims about the potential of trees to offset the effects of greenhouse gases on Earth's rising temperatures. Students investigate how a tree exchanges gases with the atmosphere and through the processes of photosynthesis changes CO^2 into O^2 and how structures in the tree transport water and nutrients. Students plan and conduct an investigation into where the carbon goes that a tree takes in from the atmosphere and how a tree makes wood that stores carbon for its lifespan.

Students apply what they have learned about how trees store carbon to a design challenge, in which they compare planting trees to a solution to climate change of their choosing.

Performance Expectations:

HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

HS-LS1-3: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

HS-LS1-5: Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS1-6: Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen

HS-LS2-2: Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS2-6: Evaluate the claims, evidence, and

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from sugar molecules may combine with other elements to form amino acids and/or other large carbon based molecules.

HS-LS1-7 Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.

HS-LS2-1: Use mathematical and/or computational representations to support explanations of factors that affect the carrying capacity of ecosystems at different scales.

reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-LS2-8: Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.

An Equity-Focused, Research-Based Biology Course

The inquiryHub biology curriculum supports *culturally responsive teaching* in three key ways. First, students have had input into the choice of anchoring phenomena. The team used evidence from student surveys to select phenomena, examining data about which phenomena most interested girls, Latinx and African American students, and emerging bilingual students. Second, the curriculum supports teachers in eliciting and making use of students' own questions and their experiences in instruction, which supports student motivation and agency (Harris, Phillips, & Penuel, 2011). Student questions related to anchoring phenomena are recorded on a Driving Questions Board, which becomes the basis for students' progression through each unit. Third, through design challenges, students have an opportunity to use engineering practices to connect what they are learning in science to problems of personal, community, and global significance. When students see how science and engineering are relevant to their everyday lives, they come to value and identify the scientific enterprise more (National Research Council, 2012). Sometimes, we refer to our curriculum as "5D" because in addition to the 3 dimensions of core ideas, practices, and crosscutting concepts, we emphasize connecting to interests and identities, two additional dimensions identified as core to promoting equity in science education (National Research Council, 2009).

The storyline approach to unit development supports pedagogies that have a broad base in research on how students learn. The pedagogical approach of presenting problems *before* students have had a chance to learn core ideas and creating a need for developing an understanding of core ideas, for example, is grounded in studies of what is needed to support learning transfer (Bransford & Schwartz, 1999; National Research Council, 1999). The problem-based approach, moreover, has proven more effective than traditional teaching approaches in improving achievement on 3D measures of learning (Penuel, Harris, et al., 2015).

Research on the ihub curriculum is ongoing, as part of our long-term research practice partnership. Each year, we revise the units on the basis of evidence related to usability (from teachers), the student experience (from exit tickets), and student outcomes (from transfer tasks). Each year from participating classrooms, we gather pre- and post-test data to analyze growth in the curriculum and present results to the district and submit our studies for peer review.

The curriculum is being used in a wide range of DPS schools, including alternative schools, innovation schools, and schools with high percentages of English learners. We have shown through exit ticket data that 60% of the time, students perceive lessons to be personally relevant to them when implemented in DPS classrooms (Penuel et al., 2017). In addition, students show significant gains on tests of student understanding from pretest to posttest.

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ENGAGING IN PRACTICES OVER TIME

In storyline units, students engage in science and engineering practices in order to answer the overarching unit question. The practices are *how we work together to figure out* explanations of phenomena and solutions to problems. They are neither a replacement for the scientific method or discrete skills we teach students. Rather, students develop an understanding of the practices through engaging them about what they are and about how and when to use them. In the units, students engage in all eight science and engineering practices in an integrated fashion, experiencing how they can work together to explain phenomena and solve problems.

The target learning goal is for students to gain a *grasp of the practices* (Ford, 2008) as described in Appendix F of the NGSS and *A Framework for K-12 Science Education*. Appendix F describes the elements of each practice appropriate for each grade level band. By the end of the biology course, students will have developed a grasp of each element of the practices. The curriculum follows a learning progressions approach (Rivet & Duncan, 2013) to support the development of the practices, building understanding incrementally through using them to explain different phenomena. Examples of support for student engagement in practices include:

Asking Questions: At the outset of each unit and at the beginning of every class, students ask questions to guide investigations of phenomena.

Defining Problems. When students face a design challenge, they identify criteria and constraints a solution must satisfy.

Developing and Using Models. Students engage in incremental model building for anchoring phenomena. They use models to make sense of phenomena, synthesize evidence from investigations, and make predictions about what will happen in the future. Students make use of digital tools to support model building and model exploration.

Planning and Carrying out Investigations. In contrast to units where students follow prescribed steps in an investigation, many investigations require students to plan and carry out investigations using materials provided in the curriculum. The investigations include controlled experiments in the lab, observations outdoors, and studies that use computer simulations. Investigations are planned and carried out in order to gather data needed to fully explain a phenomenon.

Analyzing and Interpreting Data. Students use real scientific datasets to investigate phenomena. The data are presented in varied forms that students would encounter in scientific journals, and student activity sheets provide questions to help them make sense of the data.

Using Mathematics and Computational Thinking. Students engage with grade appropriate mathematics in units, such as statistics, functions, and rational number reasoning. In addition, the units make extensive use of a modeling tool, NetLogo, to help students gain insight into computational models of complex biological systems.

Constructing Explanations. Students regularly construct explanations as part of daily lessons using multiple formats, including in the Claim-Evidence-Reasoning (CER) format.

Designing Solutions. Students engage in a human-centered approach to engineering design to design solutions to culminating design challenges that are part of each unit.

Engaging in Argument from Evidence. Through discussions and in writing, students construct and critique arguments in which students engage with competing explanations for phenomena they are investigating and with competing solutions to design challenges.

Obtaining, evaluating, communicating information. All lessons involve students in scientific forms of writing. Students read and interpret scientific texts and learn to evaluate information they obtain from the internet for accuracy and for relevance in answering questions about phenomena.

ASSESSING STUDENTS' GRASP OF SCIENCE AND ENGINEERING PRACTICES

We have developed extensive support for assessing students' grasp of practices (see Shepard, Penuel, & Pellegrino, 2018, for an extended description of these supports). All assessments evaluate students' understanding of some element of a scientific practice. In addition, the materials include a tool for teachers to develop their own assessments, the *Science and Engineering Task Formats*, which teachers across the country have used successfully to build assessments of scientific practices. As part of each unit, there is an *incremental model tracker,* which helps students identify how the day's lesson is helping build toward an explanatory model of the anchoring phenomenon. Teachers can monitor progress toward students' grasp of the core practice of developing and using models through culminating assessment tasks for each "bend" in a storyline and the accompanying scoring guides and rubrics. Students are expected to construct an explanatory model that includes all elements of a scientific model, that is, accurate descriptions of the components, interactions, mechanisms, and boundaries of the system being model.

A unique feature of these assessments is that they are integrated fully with DPS Science Competencies and Performance Indicators, and a DPS model SLO: "Developing and Using Scientific Models.". The rubrics developed for student models allow for evidence to be collected from student work to show progress toward student mastery of the practice/competency/SLO.

INTEGRATED TECHNOLOGY

inquiryHub biology curriculum was developed from the ground up as a digital curriculum for both teachers and students. It is implemented as a set of Google Drive files (slides, docs, sheets), with accompanying videos, images, and other curricular materials. Curricular materials are accessed via any web browser and can be copied, shared, and edited (see Open Source Materials: Licensing). Within Google Drive, the reference versions of the curricular materials cannot be edited; teachers must first copy a document before sharing or making changes. Certain materials, such as student handouts, are designed to be easily printed. All materials were iteratively designed and tested over three cycles, with teachers from DPS, Connecticut, and Illinois.

Deployment Options and Recommendations

We recommend classrooms have a student:device ratio of 3:1 or lower. In the field study in DPS, many of the classrooms were using 3:1 Chromebooks. The curriculum was provided to teachers via two routes: directly from a set of Google Drive files and via the Schoology system provided by DPS. We recommend providing both alternatives again.

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Authentic Tools for Work and Science
Google Drive is widely used by schools, universities, government, and business. Developing students' confidence and facility in this *office and personal productivity suite* will help to prepare them for higher education and the workplace. This suite of tools will support students to engage in science and engineering practices. For instance, by using Docs to develop explanations or plan an investigation, using Sheets to analyze data and construct visualizations, or by using Slides to develop a presentation or diagram. All document types native to Google Drive support real-time collaborative authoring and editing, a critical feature for supporting team work for both teachers and students.

Scientific modeling is a core science practice in the NGSS. To support this practice, inquiryHub biology curriculum also includes several open access *scientific modeling tools* to enable students to develop their own scientific models, to use models to conduct what-if experiments, and to construct arguments and explanations using their models. We make extensive use of freely available tools for modeling complex biological systems (*NetLogo*) and for modeling relationships in a schoolyard (*EcoSurvey*).

Infographics are visual representations of information, data or knowledge intended to present information quickly and clearly. Research suggests that *making infographics* can support students to develop explanations of STEM phenomena and it is an important 21st century scientific communication practices (Polman & Gebre, 2015). inquiryHub biology curriculum units include opportunities for students to make infographics and we provide several technology options that students can use, ranging from general purpose applications (Google Sheets) to specialized applications designed specifically to support infographics development and sharing (VennGage). VennGage offers free access to a reduced feature set version.

CRSPR-Cas9 and other genetic engineering technologies are core topics developed in our genetics unit. Students learn how to use world cafe techniques to discuss the ethics of genetic engineering and other critical questions. World Café is a *"social technology" for engaging diverse peoples* in deliberative dialogue about challenging or controversial topics. Future versions of the genetics unit could provide students with hands-on bio-engineering opportunities as those technologies become more accessible and affordable.

inquiryHub biology curriculum also includes *physical specimens* such as tree rings. Districts will need to purchase a modest amount of other materials and supplies to support student investigations. Materials and supply lists are provided.

Interactive Student Experience Feedback
inquiryHub biology curriculum includes a set of student electronic exit tickets (SEETs) for use throughout the year. These exits tickets ask students to answer 4 to 6 questions and take 3 minutes or less to respond to. The questions are designed to probe *students' experience of coherence, relevance,* and *belonging* in science classrooms. No class list is required; teachers can simply provide their students with a URL to the exit ticket. A series of graphs and charts are generated from student responses and provided to the teacher. These are intended to serve as a practical measure that teachers can use to reflect on and improve their instruction.

DISCUSSION STRATEGIES

Productive talk is the glue that connects practices to one another, practices to Disciplinary Core Ideas (DCIs) and crosscutting concepts and ideas (CCC), and also the way that the class makes sense of what they are figuring out.

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There are four basic types of discussion included in the units that support students' science learning in ways that are consistent with the Next Generation Science Standards:

Generating and Prioritizing Questions Discussion
Initial Ideas Discussion
Building Understandings Discussion
Consensus Building Discussion

These recur throughout the units, so that students and teachers alike can become familiar with them. The different discussion types serve different purposes. Descriptions of each discussion type include guidance for the teacher as to its purposes, occasions when it may be useful, specific "talk moves," and how to use the moves within a classroom routine.

Within lessons, specific prompts for sparking discussion are provided to the teacher, as are potential student responses to the prompts.

Supporting English Language Learners
The units include a number of materials to support students learning English. All student activity sheets will be translated into Spanish in summer 2018. Extensive use of strategies to expand "thinking time" for English learners through think-pair-share strategies are integrated into individual lesson plans. In professional development, we link to different tools for supporting equitable participation in discussion found on the *STEM Teaching Tools* website (http://stemteachingtools.org).

ASSESSMENT OPPORTUNITIES

As part of our research-practice partnership, we have developed a system of assessments that is grounded in a sociocultural theory of learning (Penuel & Shepard, 2016) and that adheres to the recommendations of the National Research Council (2014) report, *Developing Assessments for the Next Generation Science Standards.* This 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.

Our system of assessments includes seven basic types of assessment:

Summative **transfer tasks** where, at the conclusion of the unit, students apply what they have learned to explain a new phenomenon or solve a new problem related to the core ideas they are studying.

A **culminating assessment lesson** for each unit bend in which students build an explanatory model of the anchoring phenomenon. A rubric for analyzing student models lessons that links up to the district SLO form is included.

An **incremental model tracker** that students add to periodically to help them put pieces together from individual lessons and work toward an explanatory model of the anchoring phenomenon. This facilitates self- and peer assessment.

Formative **activities to generate and prioritize student questions** that the class agrees must be

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answered, in order to explain the anchoring phenomenon. These activities produce an artifact--the Driving Questions Board--that is a record of students' own questions and that serves as a means to help students track what they are learning.

Instructional routines for **capturing what students figure out** at the conclusion of each lesson. These are related back to the Driving Questions Board.

Student electronic **exit tickets** that are integrated into lessons to provide easy-to-grade questions related to the day's lesson and also elicit students' perceptions of the coherence and relevance of the day's lesson to their daily lives.

An **interest survey** we use each time we develop a unit. The survey results are disaggregated by gender, race, and home language to guide selection of anchoring phenomena for units.

Through this set of assessments, the unit provides opportunities for assessing students' individual or independent mastery of the performance expectations as well as for assessing the group's progress in explaining anchoring phenomena or solving design challenges.

DIFFERENTIATION STRATEGIES

The materials draw on basic principles of Universal Design for Learning (UDL; CAST, 1998). UDL calls for curriculum designers to create materials for the widest possible range of learner capabilities that are usable as is or with limited modifications. The curriculum includes multiple modes of representation of content, through text, image, video, and sound through which students can access ideas. The curriculum provides opportunities for different forms of expression, in speech, writing, in drawing, and in manipulating computer models. Third, there are multiple modes of engagement through the eight science and engineering practices.

In addition, additional information throughout the units include references to differentiating activities for both gifted students and students labeled with disabilities. Readings include scaffolds for all readers that help them access challenging and authentic scientific texts.

For gifted students, the use of a Driving Questions Board provides a basis for independent investigations related to the anchoring phenomenon that allow these students to contribute to the class while exploring novel questions related to their own interests.

What Is a Storyline?

Each unit is a storyline. **A storyline is an instructional unit that is a coherent sequence of lessons, in which each step is driven by students' questions that arise from their interactions with phenomena.** A student's goal across a storyline should always be to explain a phenomenon or solve a problem. At each step, students should make progress on the classroom's questions through science and engineering practices, to help figure out a scientific idea. Each piece they figure out should add to the developing explanation, model, or designed solution.

Each step may also generate new questions that lead to the next step in the storyline. Together, what students figure out helps explain the unit's phenomena or solve the problems they have identified. A storyline provides a coherent path toward building disciplinary core ideas and crosscutting concepts, piece by piece, anchored in the students' own experiences and questions.

Often the importance of a particular problem or idea is clear to the teacher, but not to the students. For example, the teacher knows how learning about the cell will help with important biological questions, but to the students, they are learning about cells because that's the title of the current chapter in the textbook. The teacher may know how a particular chemistry experiment will help understand something about conservation of matter, but to the students, they are doing the experiment because they are following the directions.

In a storyline, the coherence is designed to make sense from the students' perspective, not just the teacher's. When a storyline is coherent from the students’ perspective, on any given day, a visitor to the classroom should be able to walk over to a group of students and ask them:

- ***What are you working on?***
- ***Why are you working on this?***

Students should be able to answer by describing a question they are trying to figure out or a problem they are trying to solve, and not just say because the teacher told them to do this. They should be able to explain how they helped the classroom community decide a plan of action.

Figuring out is not a process you can do by jumping from topic to topic or from lab to lab. Practices are more than just technical skills, like learning to use a microscope or when to wear goggles. Practices refer to how a community works together, guided by common goals, norms, and language to make progress. Science and engineering practices guide the work with phenomena and problems so students can develop, test, and refine science ideas.

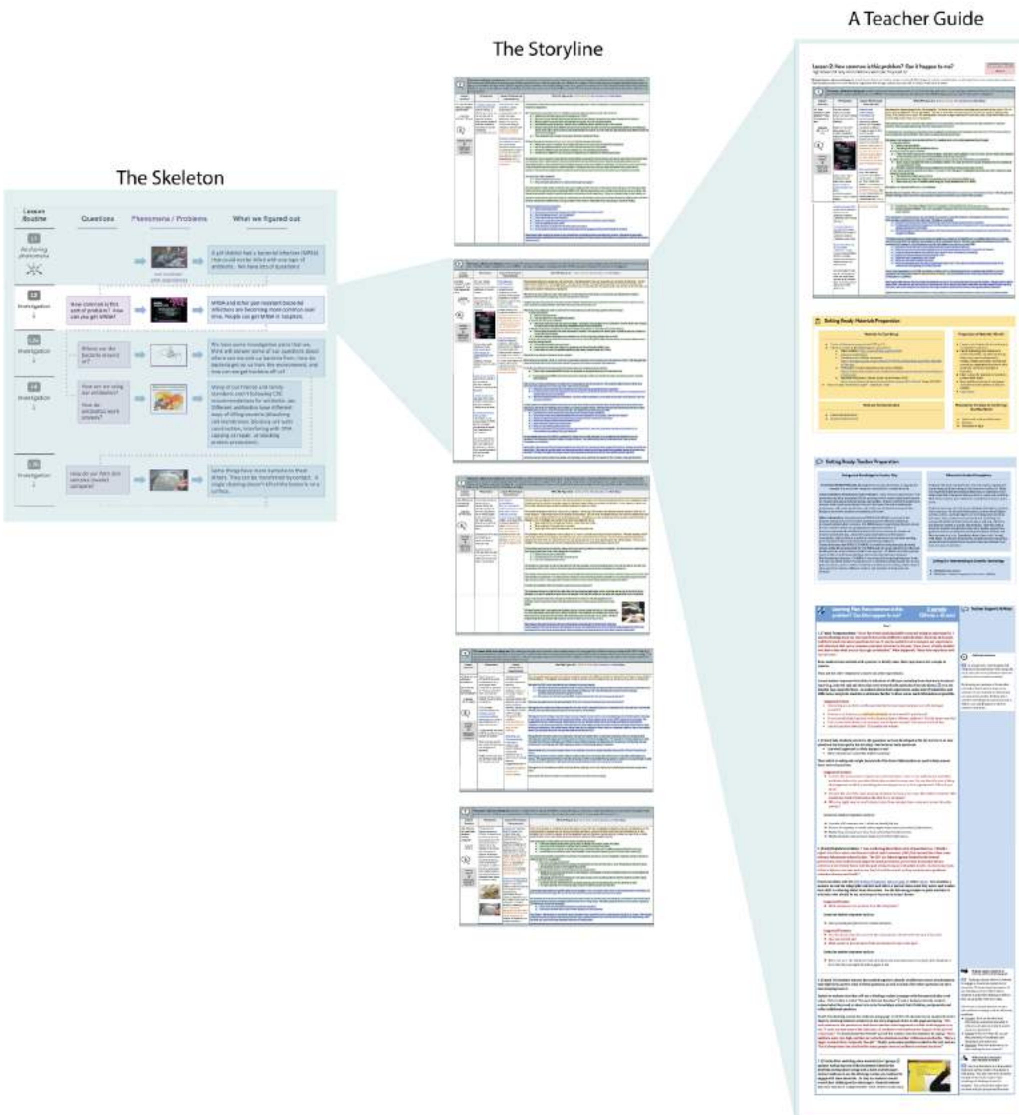
So each storyline is a path in which all the students help manage the trajectory of their knowledge building. The class as a whole, which includes students and the teacher, develop ideas together over time, motivated by questions about phenomena in the world, where each step is an attempt to address a question or gap in the classes' current explanatory model. **The storyline approach supports students' agency in sensemaking:**

- **WE** figure out the science ideas.
- **WE** figure out where we are going at each step.
- **WE** figure out how to put the ideas together over time.

So, how will WE orchestrate our sensemaking? The answer is a storyline. The bottom line is that a storyline reflects a way to support sensemaking that is coherent from the students perspective. A storyline illustrates how we can help students extrapolate a general model for science ideas out of exploring case studies, rather than teaching them the science ideas first and then seeing the ideas in action by looking at examples.

What Unit Planning Resources Are Available?

There are three main unit planning resources available; the **skeleton**, the **storyline**, and the **teacher guides**. As suggested in the diagram to the right, each of these resources, provides progressively finer detail about what is in a particular lesson.



The skeleton includes the question that students will investigate in each lesson and photo/diagram of one of the related phenomena they will investigate in that lesson. It also includes a two to four sentence summary of what students figure out for that lesson. In the diagram above, this portion of the skeleton shows this for the first five lessons of the unit.

The storyline provides a more detailed description of what students will investigate in each lesson, with each lesson summarized in its own table. Each table is 1-2 pages in length, and is referred to as the roadmap for that corresponding lesson. Each roadmap includes lesson level performance expectations, connections to the previous lesson and the next, and a more detailed narrative of what the class is doing in that lesson. In the diagram above, the first five roadmaps in the storyline are shown.

Every roadmap has a corresponding **Teacher Guide**. The first few pages of the teacher guide include a link to the storyline, a synopsis for for that lesson including: how we got there, where we're going, needed supplies and a snapshot of the learning plan. The steps in the snapshot click through to the detailed learning plan. The learning plan provides a minute-by-minute guide to help the teacher coordinate and facilitate the learning activities. Additional details about these and other supports included in each lesson plan are summarized on the next page.

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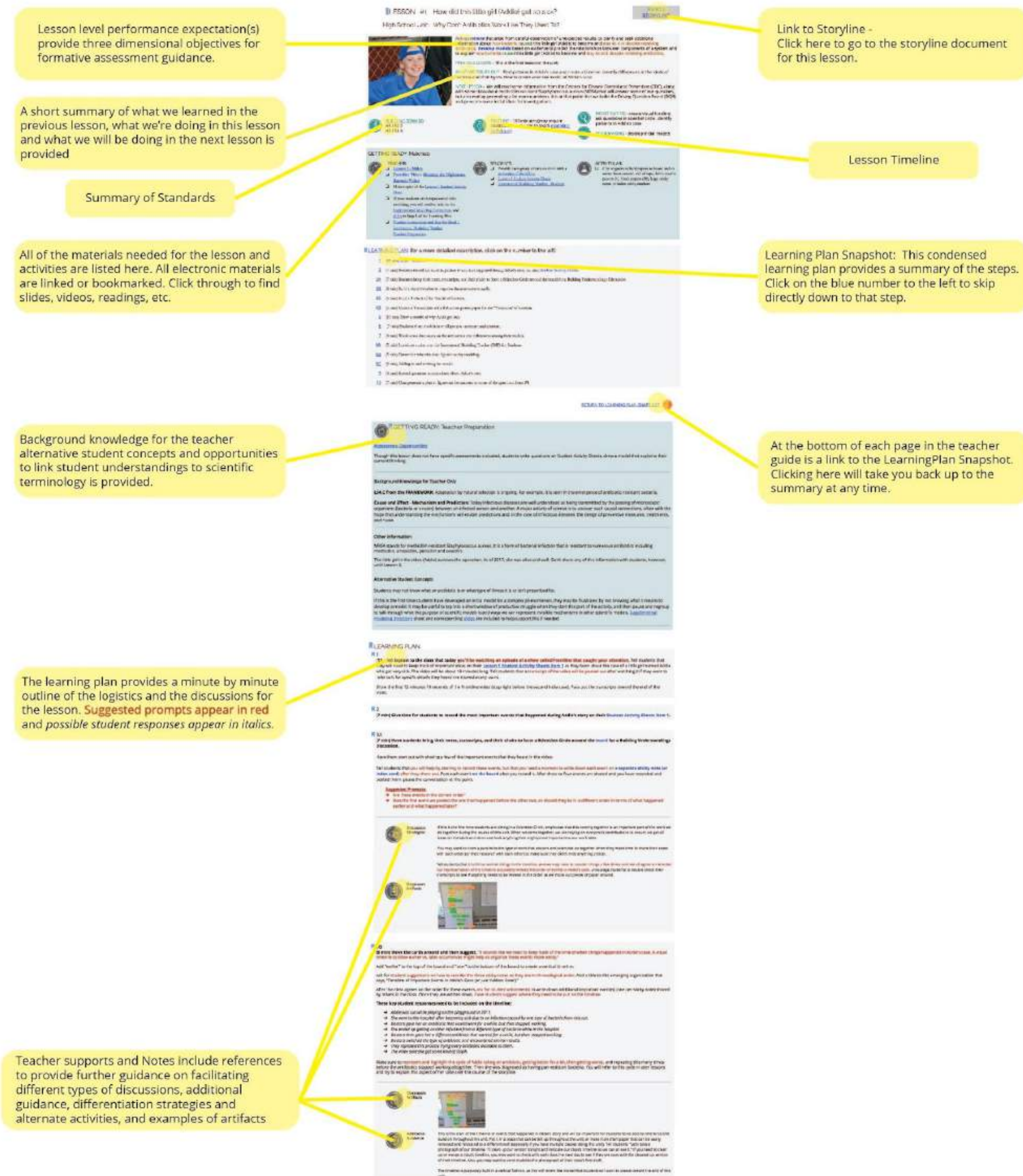
What Lesson Planning Resources Are Available?

Each Teacher Guide for every lesson has a similar structure, which is outlined in the example shown below. Each lesson may include additional resources, such as student activity sheets, data packets, video clips, readings, home-learning assignments, and projected images. All related resources for the lesson will be referenced and linked to (if applicable) in the Teacher Guide.

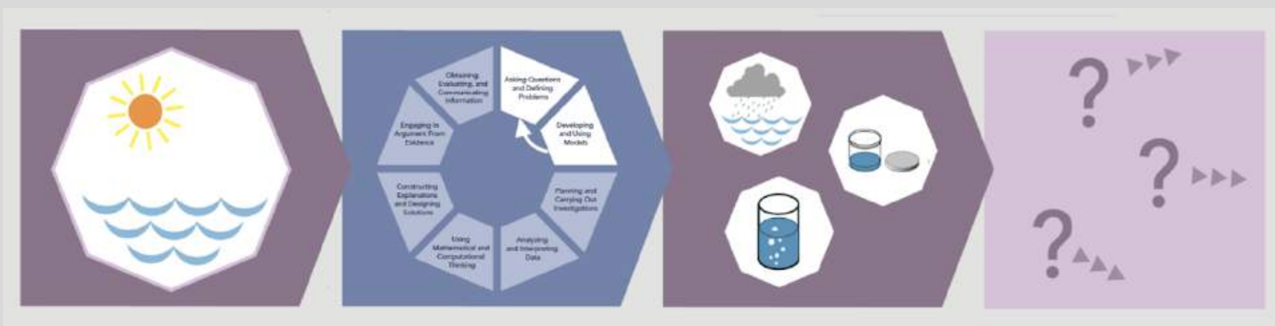


How Can Teachers Use Similar Instructional Routines Across Units & Lessons?

If you look at the left hand column of the skeleton you will see reference to a series of routines used with each lesson. **Embedded in our curriculum materials are five instructional routines that are used to support three-dimensional learning throughout this unit and can be applied to other units of instruction.** These routines are not meant to be interpreted as a step-by-step guide, but rather as dynamic elements used in NGSS Storylines to achieve the goals of three-dimensional learning outlined in *A Framework for K-12 Science Education* and with the Next Generation Science Standards. Here we attempt to summarize and make the design rationale of storylines explicit using each of the five routines. Use the far left column in the Storyline Skeleton to identify where in the unit each routine is used.

ANCHORING PHENOMENON ROUTINE

Explore Anchoring Phenomenon	Attempt to Make Sense	Identify Related Phenomena	Develop Questions and Next Steps



There are four main parts of the Anchoring Phenomenon (AP) Routine, which occur at the start of every unit:

Explore Anchoring Phenomenon
Every instructional unit should start with some puzzling phenomenon that students experience. In this section, students explore that phenomenon in some way. The question the class is working on is *What do we notice?* For example, students might make observations, look for patterns, or create a timeline of events that occured. The purpose of this section is for students to recognize the interesting events going on and to publicly, as a learning community, acknowledge aspects of the phenomenon that require key pieces of target DCIs to explain.

Attempt to Make Sense
Students should try to come up with an explanation, model or some other reasoning to explain why or how the phenomenon under investigation is happening. Oftentimes, people view this attempt to make sense of the phenomenon as pointless. For example, they may think that we know the students don't understand what's going on, so why take the time for them to try and come up with a reason to explain the phenomenon when it's going to be wrong? The intention of this section is not to come up with the "right" answer. **The purpose is to start to stake out the territory of what they don't know yet so that later, we can up come with a plan to figure out those pieces.** It's important that each student tries individually to attempt to make sense of the phenomenon and then go public with his or her ideas. **Diversity in our sense-making ideas here is very productive!** It helps create the sense that we are all not on the same page, and that there is stuff here that needs to be figured out. The role of the teacher in this stage is two-fold: 1. To help students get their thinking down on the page, regardless of if it's right or

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wrong and 2. To push students to come up with a mechanistic explanation about what is 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.

Identify Related Phenomena

The goal of NGSS storylines isn't just to solve a single mystery about one phenomenon; **the goal is to build up disciplinary core ideas and crosscutting concepts (CCC) and ideas that can be applied to a range of events in our world**. It's important to frame brainstorming-related phenomenon around the aspects of the phenomena that lead to the target pieces of the disciplinary core ideas. The purpose of having students generate related phenomena is to broaden out the scope of what the class is really interested in figuring out and for students to have a personal connection and investment in the events explored in class. In fact, if students are not able to come up with related phenomena, then that might be a sign the anchoring phenomenon needs to be adjusted because kids won't care or relate to what the class is working on.

Develop Questions and Next Steps

In this section, the class makes a joint list of questions and action items to accomplish their mission of figuring out the driving question of the unit. 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. This may take on various forms such as a "Driving Question Board" or a "Notice and Wonder" chart. Similarly, students should be involved in thinking about ways to go about answering one or more of the questions from the class. This early on in the unit, it is not important that the ideas for investigations have a step-by-step procedure; they don't have to be what is considered an "experiment." Rather, the point is that students are identifying actionable ways to figure out answers to their questions. For example, maybe the class thinks a good way to follow up on one of their questions is to look up what experts have to say or gather secondhand data. Also, the goal isn't to come up with the perfect question or solution, anything goes! The questions and next steps that are kept on a public class record should be kept alive! Questions and next steps should be revised, revisited, and checked off as the unit progresses.

Here is a tool that can be used for this instructional routine: Anchoring Phenomena Routine Analysis Tool

NAVIGATION ROUTINE

There are two main parts of the Navigation Routine, which occur between every lesson in the unit. Think about the idea of navigation. When you are on your way somewhere and actively navigating, you have to constantly address two types of questions. First, **where are we now?** And second, **where should we go next?** These two questions happen at the beginning and end of each lesson, as well as at major decision points that may arise during lessons.

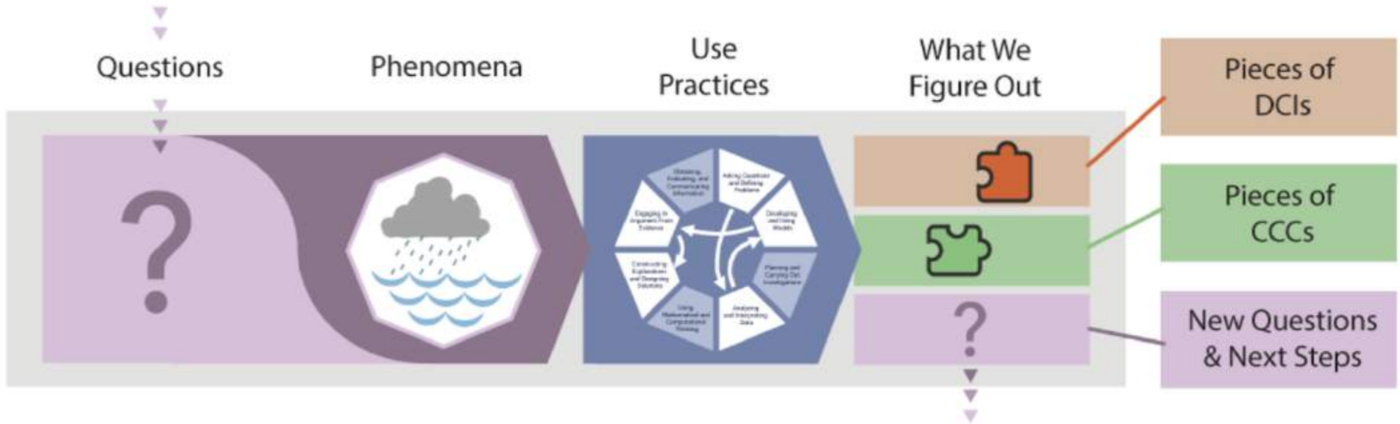
Looking Back

Each lesson begins and ends with reflection or looking back. The class asks, "What brought us to this point?" At the start of each lesson, 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 will prompt teachers or students to recall where the class left off. While this is part of the Looking Back element in the Navigation Routine, there is an important difference. Although the teacher may have to start the conversation, the work of reflecting should be done by the students as much as possible. And the purpose of reflecting isn't just to recap, it's to prime the pump so the class can think about, "Now knowing where we are, what makes sense to do next?" (Looking Forward).

Looking Forward

After the class has a chance to look back, each lesson begins and ends with planning or looking forward. The class asks, "Where do we need to go next?" When the class looks forward, the students may identify a new question or direction to pursue with their teacher. Rarely in instructional materials are students prompted to take part in articulating a logical next step to pursue. However, involving students in this work is critical for helping them develop into problem-solvers and positioning them as partners in figuring out how and why the world works.

INVESTIGATION ROUTINE



Questions regarding phenomena led 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 three-dimensional learning. We refer to this as the investigation routine.

Questions / Phenomena
Notice there is a yin yang symbol between the question and phenomena segments. This is because the question and phenomena are tightly coupled. There is a column of arrows above the question block because often times the question comes from the previous lesson, creating a need to engage in new phenomena. Or perhaps exploring new phenomena motivates the class to think of a new question. You can think of each step in the storyline as a step forward in knowledge-building, starting with a question arising from a phenomenon.

Use Practices
Students use science practices such as designing investigations, analyzing data, modeling, and argumentation to progress in their explanation. The bulk of the class' time and energy is spent in this space - using NGSS practices to make sense of a puzzling phenomenon and question. Kids should be doing the heavy lifting of figuring out.

What We Figure Out
At each step they assemble another piece of the puzzle. 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 crosscutting 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.

Connected Investigations
Two intertwined routines, the Navigation and Investigation Routines, form Connected Investigations.

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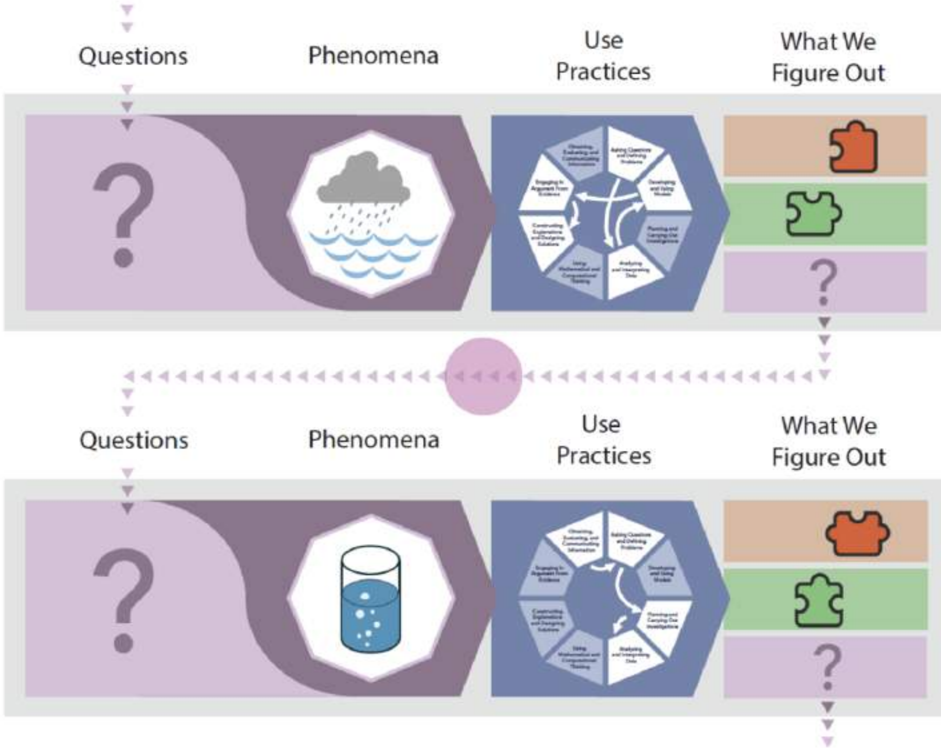
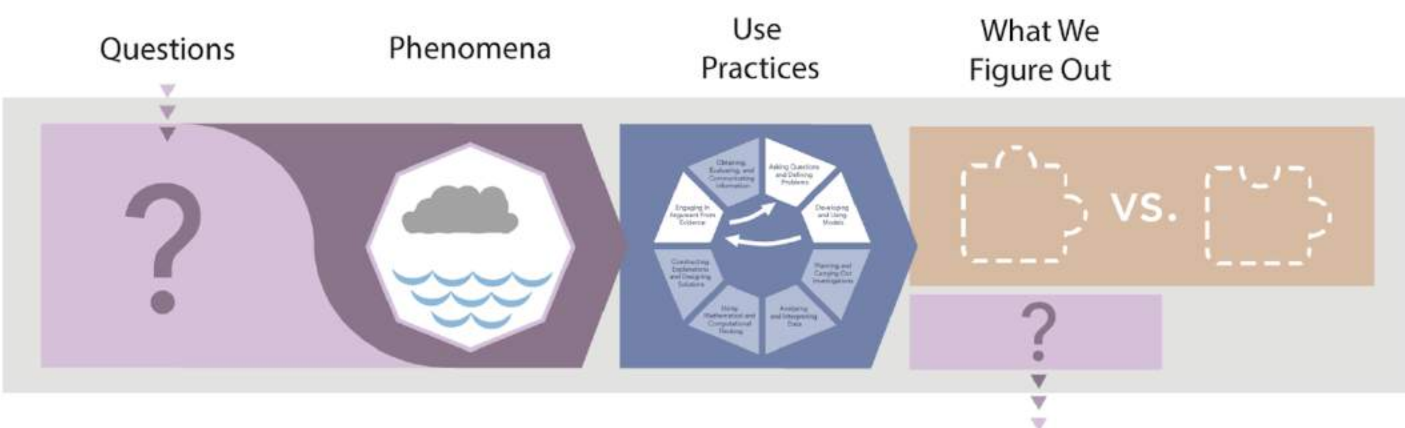


The Navigation Routine provides the connections between investigations and helps the class take stock of where they are and where they want to head next. In other words, it helps the class bring a new question into focus and set a new trajectory for the next investigation. Both Navigation and Investigation routines coupled together, are in service of supporting two types of coherence: WE figure out the pieces of the science ideas and WE decide our next steps. So together they are really supporting Connected Investigations. Here is a tool that can be used to look for Navigation and Investigation Routines: Connected Investigations Analysis Tool.

PROBLEMATIZING ROUTINE



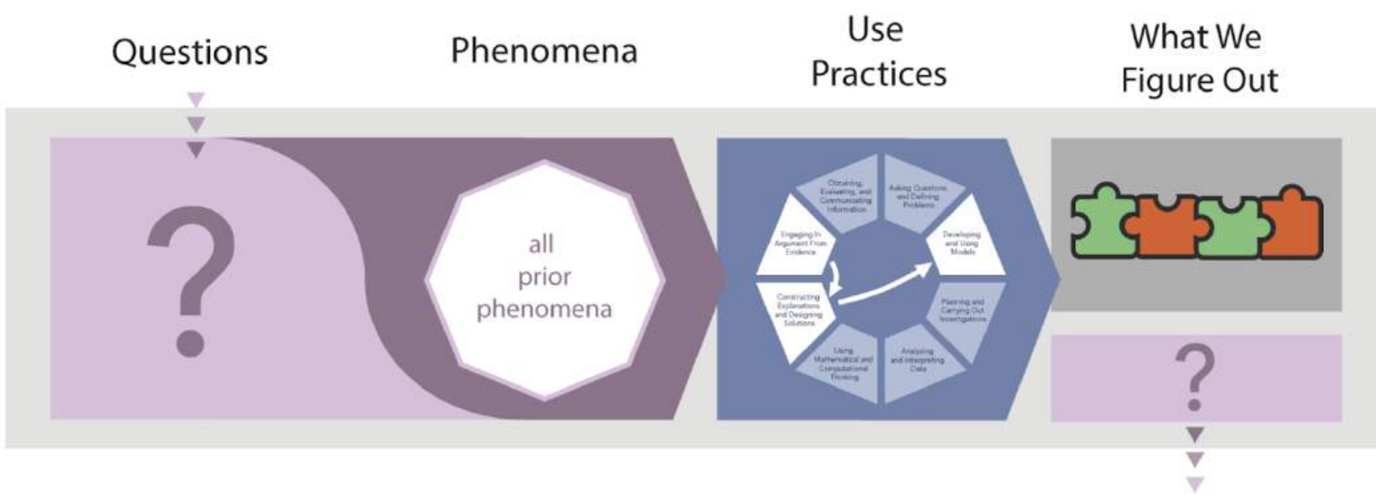
The teacher seeds, cultivates, and capitalizes on an emerging disagreement that reveals a potential problem with their current model to get students to focus on an important question that could extend their model. There are three elements of this routine.

Foreground a new question or phenomena
The teacher helps orient the learning community to a new puzzle for the class to consider that it is intentionally designed to elicit disagreement or competing explanations. The role of the teacher in this piece is to draw attention to and press the class for whether a particular key science idea they had developed could be pushed beyond what they had considered so far. This type of move is really important for NGSS. What makes a science idea a disciplinary core idea is that it can be used to explain a broad range of phenomena. Once we make some progress in explaining phenomena, we need to try to extend or break the model; so we intentionally throw a wrench in the class' progress.

Argue for competing ideas
In this section, the learning community attempts to really dig into the new puzzle and argue for their predictions or explanations. When students tried to use their model in a new context, they brought some competing ideas to the table. The role of the teacher here is to help the students to go public with their competing ideas and help the class realize they do not have consensus.

Determine a way to resolve this question
Third, students need to figure out what to work on next, and start to think about how to resolve this question. While we don't need students to articulate the detailed design of every investigation, in a coherent storyline we want the students to know why we are conducting a particular investigation and be a part of that thought process.

PUTTING PIECES TOGETHER ROUTINE



Students take the pieces of ideas they have developed across multiple lessons and figure out how to they can be connected together to account for the phenomenon they have been working on.

Take Stock
The first element focuses on taking stock of the main punchlines the class has figured out so far.
This could take different forms. Students might highlight the important discoveries they made in their science notebooks. They might fill out a summary chart of what the class figured out with regard to the question that framed each lesson. 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 step is to get all the pieces of the puzzle out on the table.

Put Pieces Together

The second element involves coming to a consensus on how to put these ideas together to explain a phenomenon or to design a solution. During this process, the class develops a physical representation of the ideas as we are putting them together; such as a diagrammatic model, a table showing commonalities across a series of cases, or a written explanation.

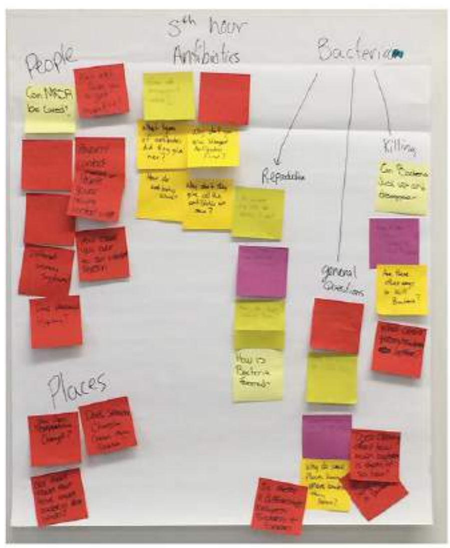
Apply This to Another Phenomenon (Optional)

Sometimes the class is ready to go further, and we see a third element of this routine emerge. After the class confidently comes to a consensus on a public representation of how the pieces fit together, they may attempt to generalize the ideas they just put together by applying them to explain new phenomena or solve new problems.

Here is a tool that can be used to look for the Problematizing and Putting Pieces Together Routines: Problematizing and Putting Pieces Together Routines Analysis Tool.

DRIVING QUESTION BOARD (DQB)

Below are examples from the Evolution Unit of the questions that students posted to The Driving Question Board (DQB). The Driving Question Board is an essential tool for developing a sense of joint mission in your classroom learning community for this storyline.



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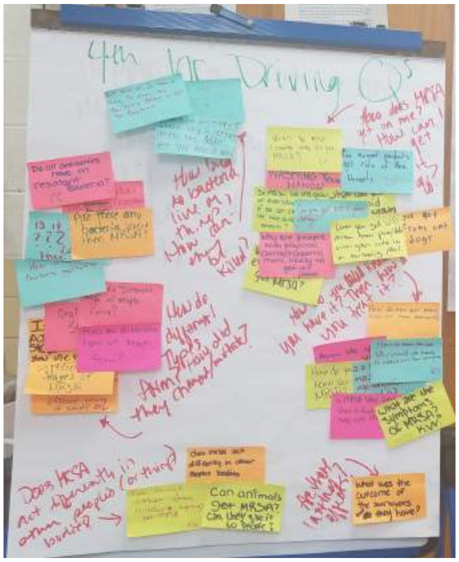

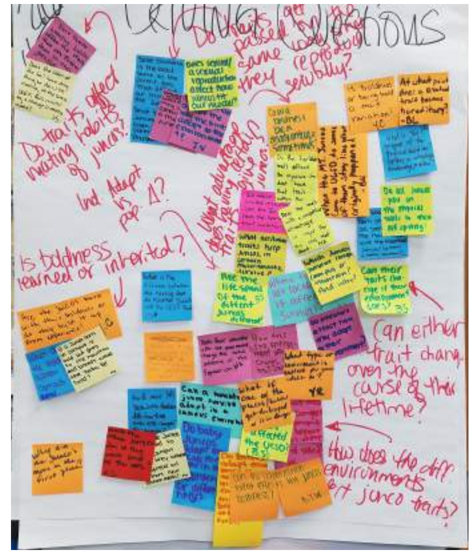

Keeping multiple Driving Question Boards active for multiple classes when you have limited wall space can be logistically difficult. One possible solution is shown to the right.

What Assessment Resources Are There?

Each unit includes an assessment folder that offers an overview of the different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self-assessment. Assessment opportunities for each lesson are included in the teacher guides.

How Can Teachers Support Different Types of Discussions?

Ideas for this resource are developed from the Next Generation Science Exemplar program and from research on fostering productive academic talk in science. Productive talk is the glue that connects practices to one another, and practices to DCIs and crosscutting concepts. Productive talk also helps the class make sense of what they figure out.

There are four basic types of discussion that can facilitate science learning in ways that are consistent with the vision of *A Framework for K-12 Science Education* and the Next Generation Science Standards:

Generating and Prioritizing Questions Discussion
Initial Ideas Discussion
Building Understandings Discussion
Consensus Building Discussion

These different discussions serve different purposes, and they are useful in different phases of a lesson or unit centered around an anchoring phenomenon or engineering design challenge. We have indicated which phases of a lesson or unit when different types of discussion might be valuable, but any type of discussion could be useful depending on what students are thinking and wondering about at the time. When planning for a classroom discussion, it is also important to think about how all students can contribute ideas and to create opportunities for individual and small group "think time."

GENERATING AND PRIORITIZING QUESTION DISCUSSIONS

Purposes

- To identify questions students need to answer, in order to solve an engineering design challenge or to develop a complete explanatory model of a science phenomenon
- To identify questions that students need to answer, to refine their understanding of a problem
- To identify questions that students want to investigate, in order to develop a piece of understanding related to a phenomenon
- To help motivate the next row(s) in an NGSS storyline
- To support students in developing a grasp of the practice of asking questions and defining problems
- To identify questions that come from students' personal experience and interests that relate to the challenge or phenomenon

Some Unit Phases When Useful
At the beginning of a unit
At the conclusion of a "bend" in the storyline

Some Lesson Phases When Useful
"*What questions do we still have?"*
"Where should we go next?"

Steps in a Possible Discussion Routine

1. Elicit Questions
2. Clarify Meanings of Questions
3. Discuss Significance of Questions
4. Prioritize the Questions

Potential Talk Moves for This Discussion

For Eliciting Initial Questions
- What questions do we need to answer to solve the design challenge just presented?
- If we want to explain this phenomenon, what questions will we need to be able to answer?
- What questions do we now have after being introduced to this phenomenon?
- What questions do we need to ask the client/partner to refine our understanding of the problem they are trying to solve?
- What questions should we try and answer with this investigation? How will answering those questions help us figure something out about the phenomenon?
- What questions should we try and answer with this test of our design solution? How will answering those questions help us figure out something we need to know to solve the design challenge?

For Prioritizing Questions
- Which of our questions are similar? What makes them similar?
- Which questions should we answer first? Why do those questions come first?
- We can't answer all of these questions at once, so which ones should we prioritize? Why are those questions important to answer, that is, ones that might help us make progress on a larger set of related questions?

Making Participation Equitable
In eliciting questions, the goal is to get as many ideas on the table as possible, so group work is a better option. Consider asking students to "write and pass" a sheet of paper around their group until they have at least 10 things. That way, all students get a chance to contribute, see others' ideas, and add their thinking in a low stakes way.

Then, use groups to prioritize questions for the class investigations. Have groups pass their written list 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.

Back to Discussion Types

INITIAL IDEAS DISCUSSION

Purposes
- To provide a supportive opportunity for students to make some sense of what may be not yet fully formed ideas (either their own or those of others)
- To support students in making tentative connections between questions being asked and the participants' experience and everyday ideas about observing a phenomenon

Some Unit Phases When Useful
At the beginning of a unit
At the beginning of a new "bend" in a storyline

Some Lesson Phases When Useful
"What are some ideas about how we can answer what we're wondering about?"

Steps in A Possible Discussion Routine
1. Provide a way for all students to surface their ideas (think-pair-share is one strategy)
2. Give people a chance to clarify one another's ideas and to ask about why people think their ideas are good ones
3. Ask a student to summarize the initial ideas that the class has
4. Ask students how they might test or further explore their ideas

Potential Talk Moves for this Discussion

When eliciting initial ideas:
- What are your ideas about how to explain this phenomenon?
- What's your "first draft" thinking about how to solve this design challenge?
- Let's see what we think about this phenomenon, using our past experiences and what we've learned in class this year as a guide.
- What experiences do you have that might help you with this phenomenon?

When clarifying ideas and pressing for reasoning:
- 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 "______"?
- Can anyone add onto this idea?
- Who has a different way of thinking about this topic?
- Can you think of an instance when this was not the case?

When asking a student to summarize initial ideas:
- Who can summarize some of the ideas we've heard today?
- Is this a complete summary? Can someone add what's missing?
- Does the summary capture our ideas accurately?

When asking students for how to investigate their initial ideas:
- What are some ways we could test our initial thinking?
- What ideas are we unsure about, that we need to know more before we can be confident in them?

Making Participation Equitable
Think about what kinds of supports your students might need to be able to *ask each other* these kinds of clarifying and summarizing 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 partner practice as a scientist and supporting them in their thinking, so you're going to ask questions, encourage them; and for now, your ideas will stay on the sideline. Then we'll switch and you'll get a chance to share your ideas as you are coached by your partner."

Tip: Have sentence starters ready for students so they know what to ask to push their partner further, but *also* have sentence starters to slow down the fast explainers, such as "Wait - you said that really fast. Can you say that again?"

Back to Discussion Types

BUILDING UNDERSTANDINGS DISCUSSION

Purposes
- To help students make their reasoning with evidence public so that other students can connect with it, critique it, and build on it if possible
- To provide the teacher and students with an opportunity to clarify which understandings emphasized in the storyline have been developed and which need further development

Some Unit Phases When Useful
After a series of lessons where a piece of understanding should have been built toward the end of a "bend" in the storyline

Some Lesson Phases When Useful
- *"What did we figure out last time? What did we wonder about?"*
- *"What have we figured out today? What questions do we still have?"*

Steps in A Possible Discussion Routine

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/solution, suggest additions to it, and critique the model/solution
3. Invite a second student or group to share their model/solution, and then invite response and critique
4. Ask students about how the models/solutions compare, in terms of similarities and differences
5. Invite the class to consider what might need to be revised in models/solutions, based on the models seen and the evidence so far

Potential Talk Moves for this Discussion

When inviting a group to share:

- What are some of the key components of your model/solution?
- 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?
- Did you consider other models/solutions? If so, what were they?
- For second group and after: How is your model/solution different from or similar to ones presented earlier?

When inviting others to critique a model/solution:

- What questions do you have for this group about their model/solution?
- Can you clarify _________ aspect of your model/solution?
- So let me see if I understand this aspect of your model/solution here. Are you saying...?
- What do the rest of you think of that idea?
- Is there anything you can add to this model/solution?
- How well does this model fit the evidence we've gathered so far?
- How well does this solution meet the criteria we identified for the solution?
- What could the group do to improve the model/solution?

When inviting students to compare models/solutions and consider revisions:

- How does group A's solution connect to group B's?
- How does these models/solutions help us make sense of and contribute to our question at hand?
- What might a model/solution look like that puts the things we think best reflects all the evidence we have so far?
- Is there any evidence that we have that none of our models/solutions can account for?

Making Participation Equitable

Consider lower-stakes ways for students to have these discussions, such as in a gallery walk where one person stays by the model to invite critique with the questions above and the 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."You can also encourage students to take a "coaching" stance here; their role is to ask questions that support others' ideas, and encourage students to speak up when something needs to be repeated.

Back to Discussion Types

CONSENSUS BUILDING DISCUSSION

Purposes

- To press toward a common (class-level) explanation or model, resolving (if possible) disagreements, different perspectives, or partial understandings
- To support public revision of earlier ideas, as new ideas are shared and as they learn information that makes visible the limitations of previous understandings held by individuals or even the class as a whole

Some Unit Phases When Useful
After a series of lessons where multiple pieces of understanding should have been built
At the end of a "bend" in the storyline

Some Lesson Phases When Useful
"What have we figured out today? What questions do we still have?"

Steps in a Possible Discussion Routine

1. Ask students to take stock of where the class has been and what they've figured out, offering conjectures or pieces of a model, explanation, or solution.
2. Ask students to offer proposals for a synthetic model, explanation, or solution
3. Ask students to support or challenge proposals, and say what evidence is the basis for their support or critique
4. Ask students to propose a modification to the model based on input from the class

Potential Talk Moves for this Discussion

During stock-taking:

- What are some things we can say at this point about our anchoring phenomenon that are supported by evidence?
- Could you clarify the link you are making between your explanation and the evidence?
- Could someone restate our question (or our charge)? What are we building consensus about?

When inviting proposals for a synthetic model/explanation/solution:

- How are these explanations similar? How are they different?
- Both groups seem to be using the same term but in a different way, could someone explain the difference?
- Could someone restate our question (or our charge)? What are we building consensus about?

When inviting support or critique:

- Who feels like their idea is not quite represented here?
- Would anyone have put this point a different way?
- What ideas are we in agreement about?
- Both groups seem to be using different language to explain the same idea, is that what you are hearing?
- Are there still areas of confusion or discontent?
- Are there still places where we disagree? Can we clarify these?

When inviting modifications to models/explanations/solutions:

- How could we modify what we have so that we account for the evidence we agree is important to consider?
- What modifications might you make to clarify any confusion or address the discontent the group feels?
- Is there more evidence or clarification needed before we can come to agreement? What is that?

Making Participation Equitable
Many students are not comfortable being the "only one" who voices a disagreement, a discontent, or a potentially incorrect idea, so ask students to think-pair-share and to carefully listen to their partners' ideas. Then ask students to think about what they heard their partners saying, and ask the room if *their partners'* ideas are represented in the class discussion. This supports all students to share, to listen, to be heard, and to be represented.

Back to Discussion Types

How Can Teachers Support the Development of Scientific Vocabulary?

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 through our storylines. While we agree that developing scientific terminology is one important goal for students, it should not undermine the heavy lift we want to engage students in. In each lesson we want students engaging in practices around a question that they feel a genuine need/drive to figure out. Front-loading vocabulary gives away the punchline for that lesson.

Once ALL students have developed a conceptual understanding of an idea in a lesson, introducing a relevant scientific term as shorthand way to reference that idea makes complete sense. It is simply a matter of timing.

Here is an example. In Lesson 5, students will notice the graph of the vibrations produced by object exhibits two interesting characteristics. A few rounds of describing patterns (individually, with a partner, and then in a whole group) will lead students to start talking about two features of these patterns that can be compared and measured. One 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 of 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 a bit cumbersome to keep referring to these features to describe the graphs in such a way, and that there are two terms that other use to refer to these features. One is amplitude and one frequency. At this point, it makes sense to consolidate students ideas by showing how these two terms correspond to the patterns they observed. From this point on, using these terms to represent these features of such graph makes total sense.

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

Key scientific terminology to connect in "just in time" as a lesson unfolds is identified in every Teacher Guide.

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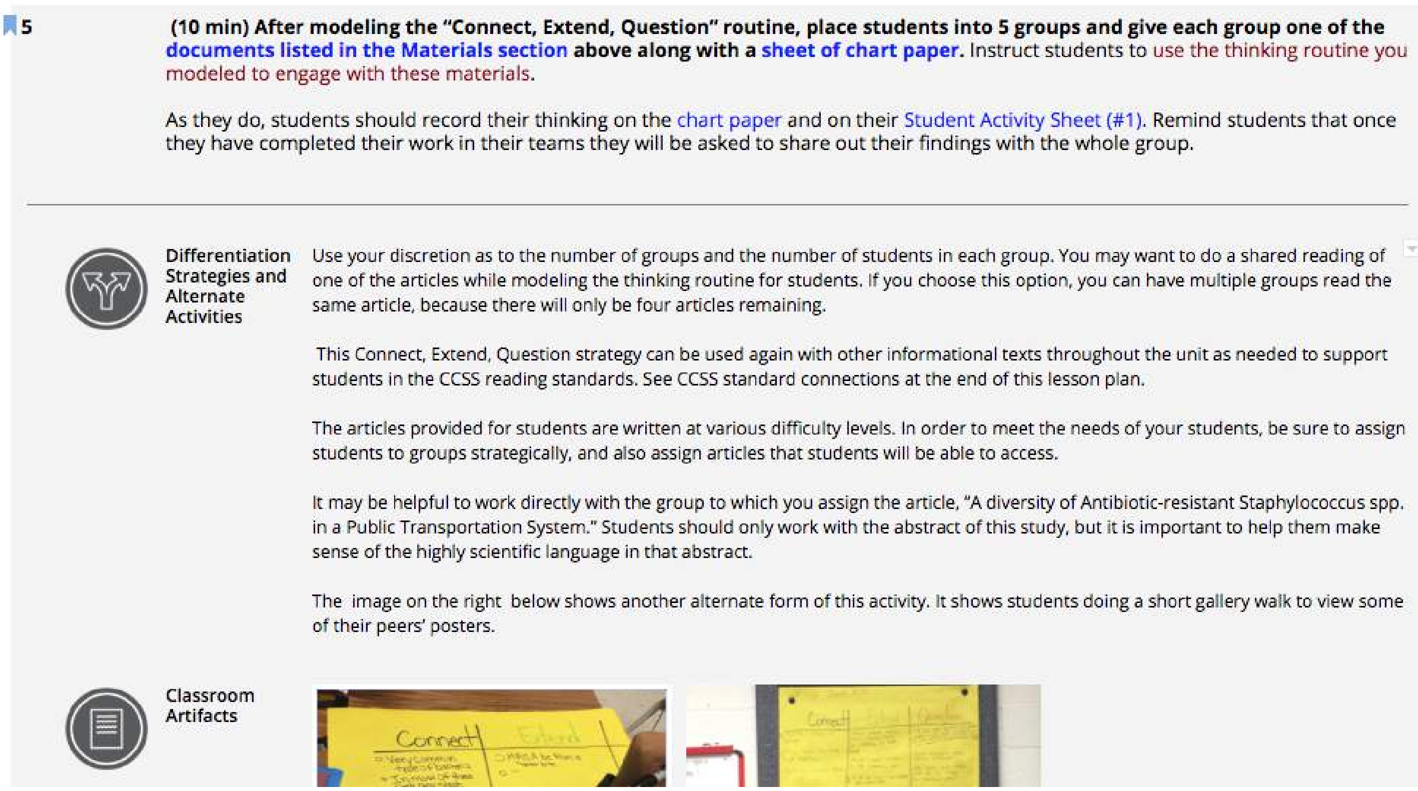
How Can Teachers Support Differentiated Instruction?

Differentiation strategies are built into individual lessons in the Teacher Supports section of the Learning Plan. An example strategy from a lesson is show below



5 **(10 min) After modeling the "Connect, Extend, Question" routine, place students into 5 groups and give each group one of the documents listed in the Materials section above along with a sheet of chart paper.** Instruct students to use the thinking routine you modeled to engage with these materials.

As they do, students should record their thinking on the chart paper and on their Student Activity Sheet (#1). Remind students that once they have completed their work in their teams they will be asked to share out their findings with the whole group.

Differentiation Strategies and Alternate Activities

Use your discretion as to the number of groups and the number of students in each group. You may want to do a shared reading of one of the articles while modeling the thinking routine for students. If you choose this option, you can have multiple groups read the same article, because there will only be four articles remaining.

This Connect, Extend, Question strategy can be used again with other informational texts throughout the unit as needed to support students in the CCSS reading standards. See CCSS standard connections at the end of this lesson plan.

The articles provided for students are written at various difficulty levels. In order to meet the needs of your students, be sure to assign students to groups strategically, and also assign articles that students will be able to access.

It may be helpful to work directly with the group to which you assign the article, "A diversity of Antibiotic-resistant Staphylococcus spp. in a Public Transportation System." Students should only work with the abstract of this study, but it is important to help them make sense of the highly scientific language in that abstract.

The image on the right below shows another alternate form of this activity. It shows students doing a short gallery walk to view some of their peers' posters.

Classroom Artifacts

Every lesson provides opportunities for students to articulate new questions and ideas for investigations that the class should pursue at the end of the lesson. Though the Teacher Guides for subsequent lessons provide ideas for how to investigate the questions that are most commonly raised by students, using novel ideas that students raise for ways to investigate these questions increases students' sense of agency, as well as providing opportunities to extend investigation design to the level that students can articulate.

At the end of most lessons, the teacher guide prompts the teacher to have students keep track of the big ideas that they figured out in their Incremental Modeling Tracker (IMT). This resource serves as a useful "single stop" location for students to look to review the big ideas they will use as they develop and revise their models. Teacher Guidance for the Incremental Modeling Tracker can be found below.

Encourage students to return to referencing either of these resources during summative assessments. Or for students who you want to challenge others, encourage them to do these assessments first without this reference.

Lastly, consider using unanswered questions from the Driving Question Board as opportunities for students to pursue additional research about any of the topics they selected, after the storyline is complete.

How Can Teachers Use the Incremental Modeling Tracker?

The Incremental Modeling Tracker (IMT) is a thinking tool that was 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 develop a model to explain the phenomenon they're working on. Students will refer back to the IMT regularly to help them prioritize ideas and revise or build on their models for what's going on in the unit. Furthermore, students will use the IMT as a way to think with others about what is important in their models.

It is important to note that this tool was designed to be a dynamic resource that students can use to progressively make sense of their ideas. We suggest that teachers use this tool to support progressive sense-making throughout the unit, and avoid using this tool as a simple note-taking activity. In the teacher guidance, suggestions are given for supporting students in using the IMT in a dynamic way to identify discoveries and use those discoveries to continually revisit, revise, and prioritize ideas in our models. In order to avoid model fatigue, teachers should not have students use the IMT every day in the same way, but rather, use it to further the sense-making when applicable. Students will use their ideas to support their work in figuring out important discovery ways to apply these ideas to their models.

The IMT Teacher Guidance with example student responses can be found in the Bend folders.

In the example IMT, each of the rows and columns has been completed with POSSIBLE student ideas. This IMT 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 the IMT reflects their own thinking at that particular moment in time. In this way, the IMT can be used to formatively assess individual student progress throughout the unit. Because the IMT 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 models without concern of being "right or wrong."

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