What Does "Implementing the NGSS" Mean? Operationalizing the Science Practices for K–12 Classrooms

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November 2016

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What Does "Implementing the NGSS" Mean? Operationalizing the Science Practices for K–12 Classrooms was prepared with support from the National Science Foundation under grant number DGE-1445543. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Suggested Citation

Pasley, J. D., Trygstad, P. J., & Banilower, E. R. (2016). *What does "Implementing the NGSS" Mean? Operationalizing the science practices for K–12 classrooms*. Chapel Hill, NC: Horizon Research, Inc.

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ACKNOWLEDGEMENTS

The Operationalizing the Science and Engineering Practices project was conducted by Horizon Research, Inc. (HRI) of Chapel Hill, North Carolina. The project was led by Eric R. Banilower, Joan D. Pasley, and Peggy J. Trygstad. A number of other HRI staff assisted with the development of this report, including Noell M. Egeland, R. Keith Esch, Meredith L. Hayes, Courtney L. Plumley, P. Sean Smith, and Jennifer A. Torsiglieri. Special thanks are due to our expert panelists who took the time from their busy schedules to assist us with this effort.

INTRODUCTION

The Next Generation Science Standards (NGSS) are based on the vision described in the Framework for K–12 Science Education—that science is both a body of knowledge and an evidence-based, model- and theory-building enterprise that continually extends, refines, and revises knowledge (National Research Council [NRC], 2011; NGSS Lead States, 2013). As such, the NGSS are composed of three intertwined dimensions—disciplinary core ideas, science and engineering practices, and crosscutting concepts—that provide a foundation for what students should know and be able to do at various grade levels.

The eight science and engineering practices outlined in the NGSS are critical components of scientific sense making. The practices are:

1. Asking questions/defining problems;
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanations/designing solutions;
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information.

Although the NGSS provide a description of what students should be able to do by the end of each grade band in relation to a particular practice (see NGSS Appendix F), currently there is limited guidance on what these practices should "look like" in the classroom.

There are two purposes for this primer. First, the primer describes what students should be doing when engaging with each science practice, defined throughout this document as the "key elements" of that practice. Second, the primer provides illustrative examples of how these key elements might play out in classrooms across different grade bands and subject areas. We think it is important to acknowledge that we do not think of the primer as "the answer" and expect both our, and the science education community's, thinking about the practices and the NGSS to continue to evolve. Our hope is that this primer will help further the conversation among the science education community (including teachers, principals, teacher educators, curriculum developers, and researchers) about what it means to "implement" the NGSS. We also want to note that our focus on the practices is not intended to diminish the importance of the other dimensions of the NGSS, but rather was an area in which we perceived a great need and was feasible for us to tackle in this project.

The remainder of the primer is organized in three main sections. The first section describes how the practices were “unpacked” and important principles learned as a result of this process. The second provides operationalized definitions and key elements of each practice. The last section presents vignettes that illustrate how students might engage in the practices, as well as cross-vignette reflections about how the practices can play out in instruction.

Unpacking the Practices

The Unpacking Process

Two methods of data collection were used to inform development of the primer. First, an extensive review of existing literature was conducted to identify and summarize current research and practice-based knowledge focused on engaging students with the science practices[1] described in the *Framework for K–12 Science Education* and the NGSS. Second, an online, multi-round modified-Delphi panel of expert practitioners was convened to identify the key elements of each practice—what students should be doing when engaging with each science practice—at different grade bands and areas of science. A description of the science practices culled from the literature review was used as a foundation for the questions posed in the expert panel. Additional information about the literature review and panel processes is provided in the appendices.

Overarching Principles

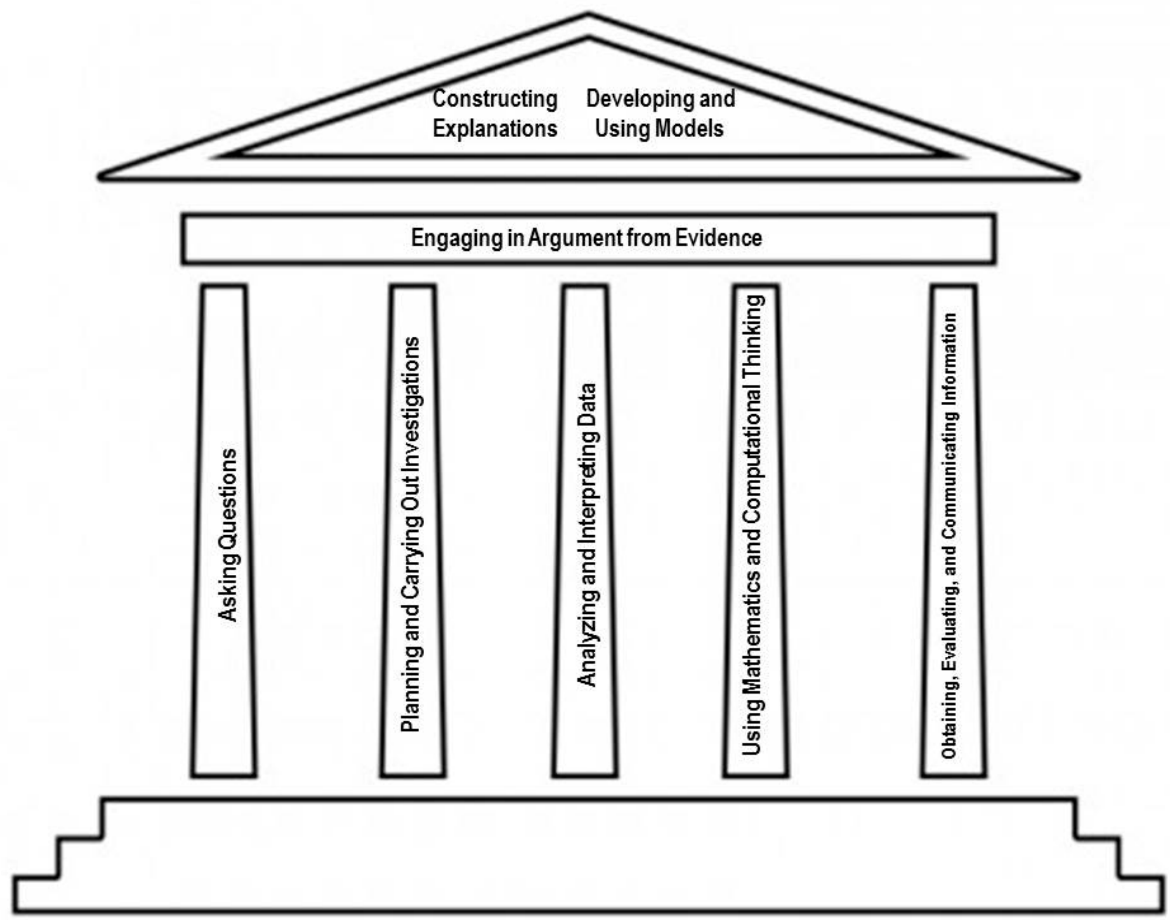
The unpacking process, and development of this primer, surfaced or reinforced a number of important principles about both the discipline of science and school science. These principles, some of which are also described in Appendix F of the NGSS, are highlighted here as they provide important framing for how the science practices are described in this document.

- ***The ultimate goal of science is the development of evidence-based explanations for, and models of, the natural world; the science practices are in the service of this goal.***

  Science is an evidence-based, model- and theory- building enterprise, and scientists engage in the other practices as part of developing models and explanations. For example, scientists do not plan and carry out investigations for their own sake. Rather, these investigations are on the trajectory to a model or explanation for a phenomenon. In addition, we see *engaging in argumentation from evidence* as an integral part of each other practice (scientists engage in argumentation when deciding on the design of an investigation, methods for analyzing data, etc.) We developed the following figure to visually represent our thinking about these relationships.

[1] Both the science and engineering practices were explored in the literature review process. Only the findings of the literature review for science practices are addressed in this document.

Hierarchy of Science Practices



- ***Consistent with the Framework for K–12 Science Education, this document takes the perspective that the overarching goal of school science is for students to gain an understanding of how scientific knowledge is generated and to engage in the development of evidence-based models/explanations for how the world works.***

Engaging in the science practices is a critical aspect of students' learning of science and about how science knowledge is generated. Developing evidence-based models/explanations for how the world works is consistent with how we know people learn ideas, i.e., people formulate new ideas based on evidence (NRC, 2005). Students also need to understand that scientific evidence is generated through a systematic and social process, which is embodied in the science practices. For example, engaging in the science practices provides opportunities for students to plan and carry out systematic data collection, consider what information would persuade an audience about a claim, and critically consider information garnered from other sources (e.g., text materials, their classmates).

- ***Engaging student purposefully in the science practices will require guidance from teachers.***

  Students will need guidance to ensure that their engagement with the practices will not only help them understand how knowledge is generated, but also lead them to evidence-based models/explanations for how the world works that are consistent with current scientific understanding (i.e., the disciplinary core ideas—DCIs). Thus, the phenomena students engage with need to be carefully selected to facilitate the development of conceptual understanding of these ideas. In addition, when students have prior conceptions that may get in the way of their developing an appropriate understanding, they will also need to engage with phenomena that allow them to understand the strengths and limitations of their initial ideas.

- ***The science practices apply to all fields of science.***

  Panelists consistently agreed that how students engage with the practices does not differ across topics/subject areas. For example, students are expected to ask questions in similar ways in biology, chemistry, Earth science, and physics. Panelists also agreed that student engagement in the practices grows progressively more complex as grade level increases. For example, a 3rd grade student may support a claim with limited evidence, but a high school student should be expected to support a claim with multiple pieces of evidence from multiple sources. However, as the practices were further unpacked, it became apparent that some key elements are too sophisticated for students in the lowest grade bands to engage with in authentic ways, particularly with some aspects of mathematics and computational thinking. (It should be noted that although some of the elements of mathematics and computational thinking may be too complex for young learners, the foundation for these elements can be built, e.g., developing simple algorithms.)

  It also became evident that as students progress through the grade bands, it may become unnecessary for teachers to explicitly engage student with some of the key elements of practices because students will have sufficiently engaged with particular aspects of a practice in earlier grades. For example, assuming students have learned to distinguish scientific and non-scientific questions in previous years, high school teachers will likely not have to emphasize this aspect of *asking questions*.

- ***There is variation in how teachers, teacher educators, researchers, and other stakeholders view the nature and role of the science practices.***

The panel process revealed some differences in how people define the science practices and describe "what it looks like" for students to engage with them. Additionally, it quickly became apparent that key terms are used in different ways. For example, panelists varied in their interpretations of what constitutes "claims," "arguments," and "explanations." To foster productive conversations around the practices, it is necessary to be explicit about how these terms are used. The following table shows how we defined a number of terms used in this primer. Although these definitions are not the only ones for these terms, they provide a frame of reference for interpreting the ideas contained herein.

Definitions of Important Terminology Used in this Primer

Phenomenon	An event that occurs in the natural world, which is often the subject of an explanation or model
System	A set of interacting components that provides a useful boundary for examining a phenomenon or set of phenomena
Inference	A logical conclusion about a phenomenon (e.g., related to how it works, what it is, what will happen) resulting from observation and reasoning
Claim	A proposed answer to a question about the natural world
Hypothesis	A preliminary claim about how or why a phenomenon occurs
Prediction	A forecast of a future event based on what is known about the natural world
Data	Information about a phenomenon or system gathered through observation or measurement
Evidence	Information (e.g., data, personal experience, general science knowledge, or science principles) used to support/refute a scientific claim about a phenomenon
Argument	The social endeavor of evaluating and justifying the processes by which models/explanations are created (e.g., experimental design, data interpretation), as well as the model/explanation itself, for a particular audience.
Explanation	A claim supported by valid and reliable evidence (e.g., data, personal experience, general science knowledge, or science principles), and reasoning for how the evidence supports the claim, to explain a phenomenon or system in the natural world (e.g., how it manifests, what causes it, relationships among variables).
Model	A representation of a phenomenon or system that shares important, relevant characteristics with that phenomenon or system and is supported by evidence from valid, reliable, and sufficient data. The ultimate purpose of a scientific model is to predict and explain a phenomenon.
Scientific Idea	A scientific claim for which a strong body of evidence exists and for which there is widespread agreement that the body of evidence supports the claim

- ***The science practices often have overlapping elements and are used concurrently.***

  In the following sections, we provide operationalized definitions and key elements for each of the eight science practices. However, we recognize that it is inauthentic to consider the practices in isolation, as they are often used in conjunction with each other. For this reason, we also provide vignettes that illustrate how instruction that incorporates the key elements might appear in different subject areas and grade bands.

  However, it is important to recognize that instruction on a particular science idea may not address all key elements within a practice. Therefore, only the key elements appropriate for the instruction in the vignette are illustrated.

- ***Students need to have opportunities to reflect on their use of the science practices.***

  In addition to having opportunities to engage in the science practices, students should also have periodic opportunities to engage in metacognition about their learning and be asked to explicitly reflect on their use of the various practices. For example, if students are creating diagrams depicting plate movement on Earth, the teacher may want to call out the fact that the diagrams are models and ask students how the use of the model is helping them construct an explanation for the phenomenon. Similarly, if students have constructed different types of models (e.g., relational models, causal models) over the course of a year, the teacher may want to have students reflect on the different models that they developed and consider the differences and similarities among them.

THE SCIENCE PRACTICES: DEFINITIONS AND KEY ELEMENTS

The NGSS, along with various research and practitioner articles, characterize each of the science practices. These sources, in conjunction with the expert panel process, contributed to the following operationalized definitions and key elements of each practice. For most practices, there was substantial agreement both among the panelists and between the panelists and Appendix F of the NGSS. The exception was Practice 5: Using Mathematics and Computational Thinking, for which no clear consensus definition or set of key elements emerged. Consequently, it is important to acknowledge that the tentativeness of the information about this practice presented in this report.

Practice 1: Asking Questions

Definition and Role in School Science

Asking questions is the science practice of generating queries about phenomena that can potentially be answered with models/explanations supported by empirical evidence. Often, additional questions emerge during the process of investigating the original question (e.g., about other aspects of the phenomenon, methods being used, proposed models/explanations).

Students may ask many types of questions in science classrooms, including questions that are procedural (e.g., "How do I use this thermometer?"), confirmatory (e.g., "Is this the right answer?"), or clarifying (e.g., "Is this what you are saying?"). However, the definition highlights that the purpose of scientific questions is to develop models/explanation about the natural world. Scientific questions are distinguished from other types of questions in that the answer takes the form of a model/explanation about a phenomenon or system that is supported by empirical evidence. The definition also highlights that science as a discipline is iterative, and that initial explanations and models may give rise to new or revised questions. In addition, the definition accounts for the fact that scientific questions can arise in a variety of ways. For example, student questions can stem from curiosity about the world, predictions about models, or findings from previous investigations.

In addition, the practice of asking questions can also serve as an integral component of other science practices. For example, a student can ask questions to improve the design of an investigation or about data obtained via an investigation and those questions can then lead to further data analysis. Similarly, a student can ask a question about a model that leads to revision or refinement of that model. Students might also ask questions in connection with the practice of argumentation, challenging one another to justify the evidence and reasoning used to support their claims.

Key Elements

The literature review and panel process yielded the following set of key elements:

A. Distinguish between scientific and non-scientific questions
B. Generate scientific questions that arise from curiosity, prior knowledge, careful observation of phenomena, models, or emerging data
C. Construct an appropriate type of scientific question for the purpose of developing scientific knowledge (note: questions may include facets of one or more of these types):
    i. Descriptive—Identify and characterize relevant aspects (features, functions, processes) of a phenomenon or system
    ii. Relational—Examine the relationships among relevant aspects (features, functions, processes) of a phenomenon or system
    iii. Causal—Identify whether a relevant aspect (features, functions, processes) of a phenomenon or system affects another and/or the mechanism for that relationship
D. Refine/revise scientific questions based on observations/data, models, and/or existing scientific knowledge to more clearly focus the question or explore emerging ideas

As was noted in the overarching principles, although students should be able to ask good scientific questions at all grade levels, their questions, and purposes for their questions, should become more complex over time. For example, elementary students should be expected to ask questions based on prior knowledge and their observations. In the middle grades, students should progress to asking questions about relationships between variables and in the service of clarifying arguments and models. By high school, students should be formulating, refining, and evaluating empirically testable questions using models and simulations.

Practice 2: Developing and Using Models

Definition and Role in School Science

Developing and using models is the science practice of constructing, employing, evaluating, and/or revising a representation (e.g., physical, graphical, mathematical) of a phenomenon to advance our ideas of how the world works. Models aid in developing explanations, identifying questions, making predictions, and/or communicating ideas to others.

The definition takes into account various forms of models (e.g., physical, graphical, mathematical), as well as ways students can engage with models (e.g., constructing, revising, evaluating). The definition also reflects the central role of modeling in science, namely that modeling is used to represent, understand relationships within, and ultimately develop causal explanations of real-world phenomena. Consequently, models are used to portray relationships among elements of a system, to test hypotheses through mathematical or computational methods, and communicate proposed explanations. Modeling is essential when phenomena are too large, too small, dangerous, or otherwise difficult to interact with (e.g., planetary systems, human body processes, molecules). An important part of this practice is being purposeful about what is and is not included in the model and the implications of those decisions for the utility of the model.

Key Elements

The literature review and panel process yielded the following set of key elements:

A. Develop an appropriate model that will best serve the intended purposes.
   i. Nature of models:
      a. Descriptive—Represent and characterize relevant aspects (features, functions, processes) of a phenomenon or system, including those that are not visible to the human eye
      b. Relational—Illustrate relationships among two or more relevant aspects (features, functions, processes) of a phenomenon or system
      c. Causal—Illustrate how a relevant aspect (features, functions, processes) of a phenomenon or system affects another and the mechanism for that relationship
   ii. Purpose of models:
      a. To embody or represent ideas in order to communicate to others for the purposes of informing, use as evidence for a claim in an argument, elicit feedback, etc.
      b. To make predictions or generate testable hypotheses
      c. To compare with other models
      d. To improve the understanding and/or accuracy of cause-effect relationships or causal mechanisms for a phenomenon or system

B. Identify the relevant components of the phenomenon/system, relationships among them, and/or potential causal mechanisms to include in the model based on existing scientific knowledge, evidence, and the type/function of the model

C. Identify and evaluate merits and limitations of a model(e.g., accuracy, plausibility, clarity, ability to provide insight into the description/processes/causal aspects of a phenomenon or system)

D. Revise a model based on evidence to improve its accuracy, clarity, complexity, generalizability, accessibility to others, and/or predictive power

E. Compare multiple models to determine merits and limitations of each in relation to relevant factors such as purpose, scientific evidence, intended audience, predictive power, accuracy, and/or generalizability

As with the all of the practices, it is worth noting that students do not need to engage with every key element of modeling each time they engage in the practice. However, our belief is that when students do engage in modeling, Key Elements A, B, and C should be included, as they are the foundation of this practice. In addition, it is important to note that simply creating a model does not necessary mean that students are engaging in the practice of modeling. The practice of modeling requires that students use their models for a purpose such as representing phenomena they are investigating, understanding relationships among components of a phenomenon, or developing causal explanations of real-world phenomena.

It should be noted that these key elements cannot be applied uniformly across grade bands as students' ability to engage in modeling will grow in complexity and sophistication across the grades. For example, K–2 students are expected to use, develop, and revise physical models (e.g., drawings, pictures, bar graphs) that represent events or objects, distinguishing between the model and the actual event or object that it represents. Over time, students should use, develop, and revise more complex models (e.g., graphical and mathematical), and identify limitations of models. By high school, students should be able to use, develop, and revise complex models in order to show relationships between systems and/or make predictions. High school students are also expected to develop the ability to evaluate limitations of multiple models, test models, and select models that best fit the evidence that is presented.

Practice 3: Planning and Carrying Out Investigations

Definition and Role in School Science

Planning and carrying out investigations is the science practice of determining what data will provide valid and reliable evidence for developing or testing an explanation or model of a phenomenon; specifying a process for gathering those data; and systematically implementing that process.

The definition makes explicit the interconnectedness of the practices, acknowledging that planning and carrying out investigations plays an important role in developing models/explanations of phenomena. The definition also recognizes the importance of planning and carrying out investigations for the practice of developing and using models. It is important to recognize that scientific investigations take many different forms and do not follow a single methodology. The classical "experiment" (controlling all but a single variable to examine the causal relationship between that variable and the outcome) is only one type of investigation undertaken by scientists. In many areas of science (e.g., astronomy) the use of true experiments to gather evidence is not possible and other methodologies are used.

Key Elements

The literature review and panel process yielded the following set of key elements:

A. Identify what evidence is required to answer a scientific question
B. Design different types of investigations (e.g., observational, experimental) to provide valid and reliable data that can be used as evidence to answer different types of scientific questions (e.g., descriptive, relational, causal)
C. Carefully and systematically implement an investigation (e.g., make observations/ measurements, manipulate/control variables, record data) consistent with the design of the investigation
D. Revise the design of an investigation as necessary based on preliminary findings or problems that arise with the initial design and/or procedures

To authentically engage in this practice, students must have opportunities to carefully and systematically implement investigations. Further, students should be expected to plan and carry out investigations in increasingly systematic and sophisticated ways. For example, K–2 students may collaboratively plan and carry out investigations with a significant amount of teacher guidance. In grades 3–5, students can begin to collaboratively planning and carrying out investigations that control variables. When students reach the middle grades, they should be able to collaboratively plan and carry out investigations that involve multiple variables, identifying independent and dependent variables and controls. By high school, students should be equipped to plan investigations independently, evaluate the design of an investigation, and identify potential confounding variables or effects. High school students are also expected to be able to collaboratively carry out investigations that provide evidence for and test multiple types of models (e.g., mathematical, physical).

Practice 4: Analyzing and Interpreting Data

Definition and Role in School Science

Analyzing and interpreting data is the science practice of both organizing data (the goal of analysis) and making sense of data (the goal of interpretation), often using tools (e.g., tabulation, statistical analysis, graphic representation), in order to reveal patterns and relationships that allow data to be used as evidence to support a model or explanation.

The goal of data analysis is to facilitate interpretation. The definition highlights the overarching purpose of analyzing and interpreting data, which is to reveal patterns and relationships that allow data to be used as evidence to support models or explanations. In addition, the definition acknowledges the usefulness of tools for organizing and inferring meaning from data, such as graphing, tabulation, or statistical analysis.

Key Elements

The literature review and panel process yielded the following set of key elements:

A. Construct a data display (tabular, graphical) that facilitates analysis for answering the question being examined
B. Systematically compare data from multiple trials or measurements for consistency (within and/or across groups of students) to consider potential sources of error in data collection and/or identify anomalous cases
C. Analyze the data using grade-appropriate mathematical/statistical techniques to identify patterns, trends, and relationships
D. Consider the limitations of data (e.g., missing data, measurement error) and the implications for the analysis and interpreting results
E. Interpret (describe the meaning and relevance of) the results of the analyses for the question being examined

When students engage in this practice, they must have opportunities to interpret the results of the analyses and apply them to the question they are trying to answer (Key Element E). Other key elements of analyzing and interpreting data support students' abilities to interpret data.

Students should have opportunities to expand their capabilities related to analyzing and interpreting data as they progress through the grade bands. While K–2 students may be expected to communicate information from firsthand observations via drawings, students in the middle grades should be able to construct, analyze, and interpret graphical data displays (e.g., charts, graphs, tables.) High school students are expected to progress even further, carrying out basic statistical tests and comparing and contrasting various data sets for consistency, sources of error, as well as the affordances and limitations of each data set for the claims being made.

Practice 5: Using Mathematics and Computational Thinking

Definition and Role in School Science

The science practice of using mathematics and computational thinking involves applying the thinking processes from the fields of mathematics (e.g., examining quantitative relationships) and computation (e.g., developing algorithms) to aid in the development of evidence-based explanations for, and models of, the natural world. These thought processes allow for the automation of various aspects of the scientific endeavor related to data collection, creating and using models, organizing and analyzing data, supporting claims, and making quantitative predictions.

This definition, gleaned from a combination of the NGSS, science education literature, and panel process, emphasizes the role of mathematics and computational thinking in supporting other science practices. For example, computational thinking can be used to develop a procedure (i.e., an algorithm) to automate data collection or to process/analyze large amounts of data. Mathematics and computational thinking also play an important role in developing models of phenomena especially computational simulations (e.g., modeling population dynamics in studying ecosystems). As with the other science practices, mathematics and computational thinking is used in the service of developing models and explanations of real-world phenomena.

Key Elements

The literature review and panel process yielded the following key elements:

A. Use mathematics and computational thinking to develop and then use models in order to explore a phenomenon (e.g., determine a mathematical relationship to represent a phenomenon, develop a computational simulation to explore a phenomenon)
B. Use mathematics and computational thinking in data collection (e.g., create an algorithmic procedure for data collection, determine criteria for sampling cases and programming a computer to identify all cases that meet the criteria)
C. Select and use appropriate mathematical/statistical/computational techniques to organize and analyze data (e.g., determining the best measure of central tendency, examining variation in data, developing a fit line, developing rules for organizing data to make patterns evident)
D. Use mathematical or computational models to generate evidence to support a claim when constructing explanations or engaging in argument from evidence

As with the other practices in the NGSS, panelists suggested that the use of mathematics and computational thinking follows a developmental progression. Further, the level of sophistication with which students can employ this practice is very much tied to their understanding mathematics concepts. For example, elementary students may be asked to organize simple data sets, and create or use graphs. By the middle grades, students are expected to create algorithms, apply simple algebra, and use tools to analyze large data sets for patterns and trends. In high school, students should be able to test and revise algorithms, applying advanced algebraic techniques and functions.

Practice 6: Constructing Explanations

Definition and Role in School Science

Constructing explanations is the process of using valid and reliable evidence (e.g., data, personal experience, general science knowledge, or science principles) and reasoning to support a claim about a phenomenon in the natural world (e.g., how it manifests, what causes it, relationships among variables).

The ultimate goal of the scientific endeavor is constructing explanations (often using models) that describe causal mechanisms for phenomena. The definition acknowledges the culminating nature of constructing explanations, setting forth a single purpose for the practice—explaining real-world phenomena. The definition also highlights the importance of using valid and reliable evidence to construct or revise explanations.

Key Elements

The literature review and panel process yielded the following key elements:

A. Develop a line of reasoning using valid, reliable, and sufficient data as evidence, as well as existing scientific knowledge (e.g., ideas, models, theories) to support a claim
B. Revise explanations based on new evidence and existing scientific knowledge (e.g., ideas, models, theories)
C. When appropriate, seek out and use multiple sources of evidence to construct/revise an explanation accounting for similar or sets of phenomena

When facilitating opportunities for students to construct explanations, Key Element A must always be included, as it is fundamental to this practice. Students must be able to use data as evidence to support a claim in order to progress to using multiple sources of evidence or revising explanations based on new evidence. Similar to the other practices, constructing explanations is a process that increases in sophistication with experience. For example, elementary students may begin by making firsthand observations to use as evidence to explain what happened, forming simple explanations. In later grades, students should begin to use models and/or representations to more fully explain how and why something happened. Middle and high school students should advance to the point of constructing explanations supported with evidence based on scientific ideas, principles, and theories in addition to any data they collect themselves.

Practice 7: Engaging in Argument from Evidence

Definition and Role in School Science

Engaging in argument from evidence is the social process of evaluating and justifying the processes by which models/explanations are created, as well as the model/explanation itself, for a particular audience. This process can also involve comparing and evaluating competing models/explanations based on their strengths and limitations, and making a clear and logical case for the strongest model/explanation.

Argumentation permeates the scientific endeavor, and involves both developing and critiquing arguments. The definition makes clear the social nature of argumentation whereby students actively consider multiple arguments (including their own), evaluate each, and justify (i.e., using evidence and reasoning) their agreement or disagreement.

Key Elements

The literature review and panel process yielded the following key elements:

Developing Arguments:

A. Determine what evidence, including pertinent details about design, implementation, analysis, might persuade an audience about a model/explanation
B. Provide, verbally or in writing, a reasoned justification to support or critique a model/explanation using valid, reliable, and sufficient evidence
C. Evaluate and articulate the strengths and weaknesses of competing models/explanations
D. Construct a persuasive case (in writing or verbally) for an intended audience for the best model/explanation for a phenomenon

Critiquing Arguments:

E. Pose and respond to questions that elicit pertinent details about the important aspects of an argument, including pertinent details about the research design, implementation, analysis, evidence, and reasoning
F. Use scientific reasoning and evidence to critique an argument, communicating this critique verbally and/or in writing
G. When providing a critique of an argument, describe, verbally or in writing, what evidence is needed to further determine the validity of a claim
H. Compare and critique multiple arguments on the same topic for whether they use similar evidence and/or differ in their interpretation of the evidence
I. Respectfully provide and respond to critiques by citing relevant evidence

Two key elements of this practice are critical when engaging in this practice. As students are developing arguments, they need to provide a justification using evidence and reasoning to support or critique a model/explanation (Key Element B). As they are critiquing arguments, they should use scientific reasoning and evidence (Key Element F). The former is the basis of developing arguments and the latter is the basis of critiquing arguments.

Consistent with the NGSS, panelists indicated that although all students should be able to engage in argumentation, they should become more skilled at using this practice in increasingly complex ways over time. For example, students in grades K–2 should be able to make a claim and support it with evidence. In grades 3–5, students should progress to supporting a claim with multiple sources of evidence. By middle and high school, students are expected to compare and critique competing arguments on the same topic, and construct, use, and/or present oral and written arguments to support or refute models/explanations for phenomena.

Practice 8: Obtaining, Evaluating, and Communicating Information

Definition and Role in School Science

Obtaining, evaluating, and communicating information is the process of reading, interpreting, and producing scientific and technical text for the purpose of developing models/explanations. This process includes: assessing the credibility of sources; recognizing salient ideas; identifying sources of error or methodological flaws; and distinguishing observations from inferences, claims from evidence, and arguments from explanations.

This definition focuses on the importance of students' being both consumers and producers of scientific information in the service of developing models and explanations, and also draws attention to the importance of clear and persuasive communication. In addition, the definition is broad enough to include multiple modes of communicating information including graphs, models, equations, writing, and discussion.

Key Elements

The literature review and panel process yielded the following set of key elements:

A. Read and gather information from scientific and technical resources such as books, articles, tables, graphs, models, and community members relevant to the science-related question
B. Evaluate the trustworthiness/credibility of one's own work and/or other sources according to their reliability, validity, consistency, logical coherence, lack of bias, and methodological strengths and weaknesses
C. Distinguish observations from inference, and claims from evidence in one's own work and/or in other resources
D. Compare and critique information obtained within one's own work and/or across multiple sources
E. Summarize patterns, similarities, and differences in the information obtained from various sources
F. Organize information in appropriate formats (e.g., written, multimedia, visual displays) obtained from one's own investigations and/or other sources in order to communicate it to various audiences
G. Produce scientific and technical text and make oral presentations that integrate qualitative and/or quantitative information and appropriate representations, from one's own or others' scientific investigations, in order to clearly communicate the results

Students can obtain, evaluate, and communicate information using a wide range of methods and resources. In the early grades, students may be expected to use observations and texts to communicate new information to explain their understanding of an idea via words or detailed drawings/diagrams. In the higher grades, students should be critical consumers of information, progressing to evaluating both the merit and validity of multiple sources of information. Students in the higher grades should also be able to synthesize and communicate information from multiples sources in multiple formats (e.g., orally, graphically, mathematically). In addition, they must assess the credibility of their sources (Key Element B), determining whether the information contained is worth considering in relation to the question they are attempting to answer. Regardless of grade level, teachers should consider what scaffolding is needed, if any, to guide students to evaluate the trustworthiness of information. It is important to keep in mind, however, that this practice (and the key elements of it), like the other practices, should be in the service of developing models/explanations.

The Science Practices: Vignettes and Cross-Vignette Reflections

This section of the primer includes vignettes illustrating how students might engage with the practices (i.e., the key elements). The 13 vignettes span four grade bands (K–2, 3–5, 6–8, and 9–12) and the major topic areas of science.[2] Although every vignette includes key elements for developing explanations and/or constructing models (consistent with the overarching goal of science), we did not try to illustrate every key element of the eight practices in each of the vignettes, as we think it is neither advisable, nor feasible, approach in planning and implementing instruction. Instruction including every one of the key elements for every unit would likely become repetitive for students and would require substantially more instructional time than is available in a school year. Rather, as a set, the vignettes for a grade band include all of the key elements that are appropriate for that grade level. In addition, given the lack of consensus among our expert panel (and the field more broadly) on Practice 5: Using Mathematics and Computational Thinking, we decided to illustrate the key elements of this practice only when it fit naturally with the other aspects of the instruction. Consequently, the elements of this practice are illustrated in a smaller number of vignettes.

It should also be noted that in each vignette, we explicitly highlighted only two dimensions of the NGSS: the Disciplinary Core Idea as described in the Performance Expectation targeted by the lesson and the science practices. It was not our purpose in developing this primer, nor did we think it was possible, to illustrate how the crosscutting concepts could play out in instruction. As Appendix G of the NGSS points out, the crosscutting concepts are lenses that can be used to guide the investigation of phenomena. Students will need multiple experiences using these lenses, as well as structured opportunities to reflect on how they used those lenses, and explicit discussion around those experiences, in order to gain facility with them. Thus, a single example of science instruction for a group of students could not illustrate appropriate and meaningful engagement with a crosscutting concept.

This section also includes cross-vignette reflections describing how the key elements play out in the vignettes for each grade band. These reflections include a table for each practice that provides an at-a-glance view of which key elements are present in the vignettes. A brief narrative follows each table detailing the connection between the key elements and the corresponding vignettes.

[2] Ideas for the vignettes came from the vast experiences of the expert panel and project staff in K–12 science education. Any similarities to specific curricula or other education programs are coincidental.

Grades K–2 Vignettes

This section includes three vignettes that illustrate how students might engage with the key elements of the practices in grades K–2. The life science vignette describes a kindergarten class learning about what plants need to live and grow. The Earth and space science vignette describes a kindergarten class learning about weather, specifically how weather changes over time and tools that can be used to measure features of weather (e.g., wind scales, thermometers, rain gauges). The physical science vignette focuses on a second grade class learning about the structure and properties of matter, particularly solids and liquids.

K–2 Life Science

A kindergarten class is halfway through a unit about the needs of animals and plants. Over the past few weeks, the class learned about what animals, including humans, need to survive. From these experiences, students concluded that animals need food to live and grow, and animals obtain their food from plants or other animals. They also learned that plants are also living things. In this portion of the unit, students are collecting data to make claims about what plants need to live and grow.[3]

Day 1:

The teacher begins by reminding students that last week they learned that animals need to eat food to live and grow. The teacher asks students to give examples of what they learned about what animals need to eat to survive. Students respond, "I learned that some animals eat plants," "some animals eat meat," and "some animals eat both." To transition to a discussion about plants, the teacher asks students to discuss the following question with a partner, "What does a plant need to live and grow?" The students generate a number of different ideas including water, sunlight, soil, and plant food. As a whole group, the teacher records the students' ideas on the board, writing the word and drawing a picture of it next to the word. After each group gives its list, the teacher points out that the things mentioned by most groups are water and sunlight. She explains that they are going to do an experiment to see what plants need to live and grow.

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[3] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

DCI: LS1.C: Organization for Matter and Energy Flow in Organisms
All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow.

PE: K-LS1-1
Use observations to describe patterns of what plants and animals (including humans) need to survive. [Clarification Statement: Examples of patterns could include that animals need to take in food but plants do not; the different kinds of food needed by different types of animals; the requirement of plants to have light; and, that all living things need water.]

Day 2:
The teacher asks the students how they could find out whether plants need water and sunlight, just water, or just sunlight. Students offer suggestions, such as:

> *I think you need to grow a plant and just give it water.*
>
> *I think you need to give a plant water and put it in the sun.*

During the discussion, the teacher helps the student keep track of their ideas and, as a class (with support from the teacher), they decide they need to grow a plant in each of the following conditions: with water and sunlight, with water in the dark, without water in sunlight, and without water or sunlight. The teacher places students in groups and gives each group a fast-growing plant that had been planted three days before.

The teacher tells students that over the next three weeks, they will draw pictures of their plant using a graphic organizer with a box designated for each day. They will also record the plant's color and overall appearance on the organizer (i.e., how healthy it looks). The teacher explains that at the end of the investigation, their collection of drawings will help them show what happened in their investigations over time. Guided by the graphic organizer, students use connecting cubes to measure plant height and shade in grid paper to represent the height to the nearest cube.

Days 3–7:
Throughout the first week of data collection, the teacher uses a document camera to project a sample of students' drawings each day, directing students to make comparisons between the drawings and actual plants. The first drawing displayed simply shows a rectangle with a line coming out of it, which the teacher assumes to be the cup and the young plant. The teacher encourages students to make suggestions for changing this drawing to make it more helpful for communicating with someone outside the class what they were doing. Students suggest that the drawing should include leaves, and that labels and pictures to show the location of the plant (windowsill or closet), cubes drawn beside the plant to show its height, and indicating the amount of water it is given each day (if applicable) would all be helpful.

Days 8–17:
Over the next two weeks, the teacher continues to guide students through discussions about their drawings, and the student drawings become more and more detailed. For instance, one student notices that the drawings do not look like the plants because they lack color and suggests that the class needs different shades of green crayons to improve their drawings. The information students provide in the graphic organizers also becomes more detailed. For example, a student notices that the soil in her cup is wet. Others students also report wet soil and some report dry

soil. Noticing these differences, the class determines that this is an important piece of information and the teacher helps them decide to use the language “dry,” “damp,” or “wet” to describe the soil. From this point forward, students include daily observations of soil moisture in their graphic organizers. As these daily discussions about improving the drawings continue, the teacher adds newly suggested components (e.g., location, height, color, soil moisture) to the class list on the board, along with pictorial representations. The teacher asks students to reflect on their drawings, discussing whether their drawings are clear and what things they are observing that cannot be included in the drawing. In addition, students compare their drawings to the drawings of other groups, commenting on differences in details and whether those differences make their drawing “more like what they are seeing” in their investigation.

Day 18:
At the end of the three-week data collection period, the groups of students are asked to examine their drawings and the data that they collected. As part of the process, each group first answers the question, “What did we observe happening to our plant?” The teacher works with each group helping them, when needed, to write the words in their summary. In addition, the teacher questions groups if they go beyond observations in their summaries. For example in the sun/no water group, the students wrote, “Our plant had brown leaves because it was burned by the sun.” The teacher uses age-appropriate language talk about the difference between an observation and an inference.

After they summarize their observations, each group presents their data to the rest of the class and posts their drawings around the room. The teacher asks each group to look at the number of blocks used to measure the height of each plant (which is shown on each drawing) and compare them across groups. The teacher asks the students, “What do you notice about the different measurements?” The students respond that the plant that had sun and water was the tallest. The teacher prompts further, “Is there anything else you notice when you look at the different drawings?” The students observe that the tallest plant is also the one that is green and has more leaves. The students determine that the data mean that the plant that received both sunlight and water was healthier than the others were. The teacher asks the students what else they notice about the other plants. One student says that the plant that had sunlight but no water, lived for a couple of days and then died. Another student adds that the plants that had water but no sunlight grew tall but looked sick. A third student also points out that the plant with no water and no light died in a couple of days. The teacher asks, “So what do you think we can say about what plants need to live and grow?” The students excitedly exclaim that plants need both water and light.

Days 19–23:
Over the next week, students further explore plants as they read grade-level appropriate texts and listen to online and teacher read-aloud books. The class reads both fiction and non-fiction texts and the teacher records the ongoing list of titles on chart paper. After reading each book, the

teacher engages the class in a discussion about whether the book was fiction or nonfiction. The teacher also supports students in identifying similarities and differences between fiction and nonfiction texts about plants. The students come to understand that nonfiction books provide information that can be used to learn more about plant growth while fiction books generally do not. Students then compare the findings from the nonfiction books, noting that many texts discuss plants' need for water and light.

Day 24:
The teacher presents students with the following question, "If we wanted to create posters to convince someone about what a plant needs to survive, what from everything we did and read would we want to include?" Most students mention that they want to share what they learned about plants' need for water and light. With teacher prompting, students comment on the importance of telling others how they carried out the investigation to discover that plants need water and light to live and grow. Students also share that they think it would be important to present their drawings to show how the plant changed over time and their graphic organizers to show the factors that led to the changes. Additionally, students mention using the information gained from their readings to convince someone else that plants need water and light.

Students begin work on creating posters, drawing upon the knowledge gained from their investigation and research. The posters use pictures and words to detail conditions that optimize plant growth, including location in relation to light and a watering plan. After completing their posters, students share them with the class and ask questions about each other's posters.

K–2 Earth and Space Science

In late spring, a kindergarten class is beginning a unit on weather. As part of a morning routine throughout the school year, students have used adjectives to describe the weather. These conversations have focused on identifying appropriate clothing and activities for different weather (e.g., skiing, going to the pool). Throughout this two-week unit, students will record observations of the weather twice a day, in the morning and afternoon, to collect data in order to explain patterns in the weather over time.[4] Additionally, students will gain familiarity with the

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[4] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

DCI: ESS2.D: Weather and Climate
Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region at a particular time. People measure these conditions to describe and record the weather and to notice patterns over time.

PE: K-ESS2-1
Use and share observations of local weather conditions to describe patterns over time. [Clarification Statement: Examples of qualitative observations could include descriptions of the weather (such as sunny, cloudy, rainy, and warm); examples of quantitative observations could include numbers of sunny, windy, and rainy days in a month. Examples of patterns could include that it is usually cooler in the morning than in the afternoon and the number of sunny days versus cloudy days in different months.] [Assessment Boundary: Assessment of quantitative observations limited to whole numbers and relative measures such as warmer/cooler.]

tools used to measure different features of weather such as wind scales, thermometers, and rain gauges.

Day 1:
The teacher begins by asking students what science questions they have about weather, reminding students of previous discussions about scientific versus non-scientific questions, a topic they have been discussing during their science lessons in the past. As students generate questions, they continue to remind each other that questions about favorite types of weather, or other opinion-based questions that cannot be tested, are not scientific. The teacher shifts the discussion by asking students how they can describe the weather. Students offer familiar adjectives such as hot, rainy, windy, cloudy, and cold. The teacher lists each adjective separately and challenges the students to think with a partner about questions they could ask that relate to each of these words. Students generate questions like the following:

Is it raining today?

Is the wind blowing today?

Are there clouds in the sky?

The teacher points out that all of these questions ask for a "yes" or "no" answer and that the answers would tell someone only about the weather today. The teacher encourages students to generate additional questions or refine their existing questions to make them about weather across days. To facilitate this process, the teacher asks students to imagine a rainy day and asks them whether all rainy days look the same. Through this process, the students are able to refine their questions with assistance from the teacher. For example:

How does the temperature change from day to day?

How does the amount of rain one day compare with the amount on another day?

How does the wind change from day to day?

How does the number of clouds change from day to day?

The class determines that in order to answer these questions, they will need to make observations about temperature, rain, wind, and the number of clouds. The teacher points out that because students will be observing the weather over several days, they may be able to notice changes. A student proposes a new question for the list, "How does the weather change?" The class realizes that this question includes the other weather features mentioned and decides that they will focus their investigation on this broader question, using the more specific questions to guide their observations.

Day 2:
The teacher provides students with individual sheets to record their morning and afternoon observations of temperature, wind, rain, and the number of clouds. Throughout the unit, the teacher models how to read the thermometer to collect temperature data (which the teacher had placed in a covered area outside the classroom door to help ensure appropriate measurements). As a class, students chart the temperature by counting and shading in boxes on a large piece of grid paper displayed in the classroom.

The class goes outside to begin collecting data. It is a relatively cloudy day and the students quickly realize that they cannot count the clouds. The teacher suggests that they may need to revise one of their specific questions (how does the number of clouds change from day to day). After a brief discussion, the class decides to revise the question to, "How much of the sky covered by clouds?" They also decide that for each day they will use one of the following descriptions depending on the amount of clouds: no clouds (none of the sky is covered with clouds, some clouds (only part of the sky is covered), many clouds (most of the sky is covered).

The teacher then leads the students to the school's flagpole and asks them to describe what they see happening with the flag. Several students point out that the flag is hanging down and not moving, but predict that it would be moving if the wind was blowing citing personal experience with flags they have seen on buildings or in their garden. Students return indoors and create their own wind flags. The teacher introduces the concept of a wind scale and with student input, creates a chart with the following scale: 0 – no wind; 1– some wind; 2– strong wind.

The teacher encourages students to think of ways they could measure rain, reminding them to think of the methods they know for measuring temperature and wind. One student suggests that they could take a piece of paper outside and then count the number of raindrops on the paper. Another student suggests that they could make a scale similar to their wind scale and describe the rain as none, some, or a lot. Other classmates point out the weaknesses of these methods, for example that the paper would quickly fill with drops and it would be impossible to count them. The class decides that they will have to measure the rain across several days in order to see any changes. One student suggests that they look at the depth of puddles after the rain, which prompts another student to suggest that they use a container to catch the rain because people may kick water out of the puddles. At this point, the teacher introduces the students to a rain gauge, and provides students with straight-sided cups that they will use to measure rainfall. The students attach a four-cube scale to the side of cup that will be used to measure the amount of rain collected. They then go outdoors to place their rain gauge in a location of their choosing.

Days 3–7:
Over the next week, students continue their twice-daily observations, noting the variation in temperature, wind, and cloud cover, in addition to the lack of rain. During morning observations on the eighth day of the unit, it is very cloudy and it starts to rain. By that afternoon it has stopped raining and students go outside to check their rain gauge, measuring the amount of rain to their nearest cube. The teacher asks groups to gather on the playground to share their findings. Most groups report rainfall amounting to less than one cube, but one distraught group reports no rain, and another group joyfully reports that their cup is completely full. The teacher asked the class to think about how some groups can have a little bit of rain and other has a lot of rain. One student suggests that someone must have knocked over the one rain gauge and spilled all the water, but another student points out the location of the group's gauge, along the wall of the building underneath the edge of the roof, probably prevented it from collecting rain. This discovery prompts other students to ask the group with the full cup where they had placed their rain gauge. The group replied that they placed their rain gauge underneath the downspout because they knew it would be the best place to catch water.

The teacher asks the class to consider whether the goal of their investigation was to collect the most rain or to measure the rain in a way that allows them to compare amounts from day to day. Students agree that the goal is to compare different amounts of rain over time and that it was not a contest to collect the most rain. The students record the amount of rain collected on their recording sheets, and the teachers suggests that the groups with empty and full rain gauges note the location of their rain gauge so that they remember that those measurements were not correct. The two groups then move their rain gauges to new locations before the class goes indoors.

Throughout the data collection phase of the investigation, the teacher helps to facilitate student thinking about changes in weather by asking them to compare their current observations with those collected on the previous day.

Day 8–9:
After students finish collecting data, the teacher provides students with the following example to assist them in making claims using their collected data:

> *It is warmer on sunny days. We found that the temperature was higher on sunny days than on cloudy days.*

With teacher support, students examine their temperature data and claim that it is usually cooler in the mornings than in the afternoons because their chart shows visible increases between morning and afternoon temperatures. The teacher then focuses students on the information that they collected about rainfall, "Was the amount of rainfall the same every day?" One student offers, "Some days it rained and some days it didn't." A second student adds, "When it rained sometimes it was a lot and sometimes it was a little." Next, the teacher asks students to look at the information they collected about the wind and cloud cover. For each, she asks the class, "Was it the same every day?" Students indicate that sometimes the amount of wind or cloud cover was the same from one day to the next, but they didn't stay the same over time.

The teacher has students look at the data they collected each day and asks, "Was the weather (rain amount, cloud cover, wind, temperature) ever exactly the same as the day before?" The students agree that they found that weather changes from day to day.

Then, students discuss with a partner what information from their observations they would share with someone in order to help them understand that weather changes from day to day. One student claims that weather changes every day, using only the data they collected about the wind as supporting evidence. His partner responds that talking only about the wind is okay, but that it would be better if they used other information they collected about the rain and clouds. Following a class discussion about the changes they observed, students record their arguments, using pictures and words as evidence in support of their claim that weather changes over time.

The teacher strategically selects student work to share, keeping in mind her desire to highlight examples that will offer opportunities for questions and respectful critiques. Using a document camera to project the student work, the teacher facilitates peer-to-peer questioning. Students most often inquire about what pictures represent, prompting their classmates to clarify their explanation either verbally or with additional information or labels. Several students recognize that most classmates only highlight one feature, such as the change in wind, but a few classmates share data from all observations. The class decides that including multiple features and presenting the related data as evidence creates a more convincing argument. When the teacher asks what information may help others understand their data, the class also decides that it may be important to add details about how and when they made their observations. The teacher gives students additional time to revise their work.

Day 10:

To conclude the unit, the teacher invites a local meteorologist to visit the classroom. During the visit, the meteorologist asks students about how they measured the weather, and students describe their thermometer, wind flags, and rain gauges to the meteorologist. The meteorologist engages students in a discussion about whether they think meteorologists use the same tools to measure the weather. Using pictures of the tools used at the local weather station, the meteorologist exposes students to more advanced technology designed for measuring wind and rain. The class acknowledges that the professional tools have many more features and provide more detailed and accurate than what they were able to collect. The meteorologist commends the students' efforts in collecting weather data and encourages them to continue.

K–2 Physical Science

A second grade class is beginning a two-week unit on the properties of matter. In this series of lessons, students collect data to develop explanations about the properties of solids and liquids.[5]

Day 1:

To begin the unit, the teacher provides each pair of students with a tray of materials that includes both solid objects (e.g., wooden block, paper clip, rock, tennis ball, crayon, sandpaper) and liquids (e.g., small plastic cups of water, vinegar, vegetable oil, corn syrup). He instructs the students to examine the items and sort them into groups that are similar, intentionally not giving directions for the number of categories or the nature of the categories. The teacher encourages students to use their senses, other than taste, to explore the items. As students explore and talk about the items (e.g., their color, shape), the teacher notes the wide variety of categories including: shape vs. no shape, has a smell vs. doesn't have a smell, and able to be poured vs. able to be rolled.

The pairs then share the categories they discussed, and the teacher records them on the board. The teacher emphasizes that they should describe objects using vision, hearing, and touch to observe properties such as color, shape, hardness, and flexibility. He focuses in on one pair's descriptive category, "able to be poured," and challenges students in all groups to sort their items by whether or not they can pour them. After they sort the items into these two categories, students work together to determine other ways the objects within each category are similar and different. Students record their thinking in their science journals.

Day 2:

The teacher asks students to review the previous day's journal entry with their partners and look at what was the same and different between the objects that could be poured and those that could not. He then facilitates a whole class discussion to help students label these two groups as solids and liquids. Following a brief class discussion about the properties of solids and liquids, the

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[5] The unit is aligned with, but does not necessarily encompass, the following NGSS DCIs and PE:

DCI: PS1.A: Structure and Properties of Matter
Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties. Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces.

DCI: PS1.B: Chemical Reactions
Heating or cooling a substance may cause changes that can be observed. Sometimes these changes are reversible, and sometimes they are not.

PE: 2-PS1-1.
Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties. [Clarification Statement: Observations could include color, texture, hardness, and flexibility. Patterns could include the similar properties that different materials share.]

teacher assigns the following quick write to students, “How can you tell the difference between a solid and liquid? In addition, give examples from your observations yesterday.” After being given time to work, students share their responses, using observations from the previous day to support their answers, and the teacher records their responses on the board. Student responses include:

> *Something is a liquid if can be poured. We saw that water and vegetable oil could both be poured so they are both liquids. But the big wooden block couldn’t be poured so it is a solid.*
>
> *A liquid takes on the shape of its container. The water in the round container looked round, and the vegetable oil in the square container looked square. The rocks in the plastic bag are solids because they didn’t take the shape of the bag. They kept their shape.*

After some discussion, the class reaches consensus and the teacher records the following shared definitions of solids and liquids: “**Solids** keep their shape and can be held. **Solids** do not flow or pour like liquids. **Liquids** take the shape of the container they are in. **Liquids** can flow or be poured easily.” The students record these definitions in their journals so they can return to them as needed.

Day 3:
The teacher provides students with a tray of cups containing small solids (e.g., rice, salt, baby powder). Reminding students of the definitions developed the previous day, the teacher asks students to categorize the materials as either solid or liquid. Students explore the materials, examining the small particles and discovering that they can be poured. The students compare pouring the new materials to pouring the liquids they examined yesterday, and, after some prompting from the teacher, realize that although the small solids flow, they do not form a level surface when poured.

The teacher directs the students to revisit their responses for deciding whether something is a solid or liquid. Students revise their responses from the previous day to incorporate their findings about small solids. Students made changes to their responses. For example:

> *When solids are small, they can be poured like liquids.*
>
> *When solids are poured, they form a pile. Liquids don’t do that.*

We looked at the solids with a magnifying glass and saw that the pieces of salt and rice didn't change their shape when they were poured. They stayed the same shape and poured into a pile.

Day 4:
The teacher gives students additional opportunities to explore the small solids by placing them in bottles and asks students to make additional observations, using their ears and their eyes. He also asks them to think about how their observations are similar to and different from the ones they made of liquids. When moving the bottles, students observe additional differences, including: some liquids drip as the bottle is turned but solids do not, and shaking solids makes more noise than shaking liquids.

The teacher posts the following prompt for students to respond to, "Is sand a liquid or solid? Use findings from your investigations of solids and liquids as evidence to support your answer." Students first discuss with a partner how they will respond to the question, including a justification, and then individually record their explanations in their science journals. Students meet with their partners again to review the different responses, discussing the accuracy of the information and the evidence being used to justify their response.

Day 5:
The teacher explains to the class that for the next few days they are going to explore some other materials. Each student is given an ice cube. The teacher asks the students to categorize the ice cube as either liquid or solid. The students identify the ice cube as a solid based on its definite shape, but notice that their desks are becoming wet with liquid. Students describe to a partner what they see happening to their ice cube, and the majority of students use the term melting. When asked to clarify what they mean by melting, most students know that melting means when a solid turns to liquid. The teacher asks students to consider why the ice cube in front of them is slowly beginning to melt, and asks them to suggest ideas for what may cause it to melt faster. One student mentions that placing the ice cube in the sun would cause it to melt more quickly.

At this point, all ice cubes are discarded and students gather for a demonstration. The teacher places one ice cube in a clear plastic cup away from the window. The teacher places another ice cube, also in a clear plastic cup, at the front of the room underneath a lamp containing a 100-watt incandescent bulb. For the next 10 minutes, students observe the two ice cubes and make drawings of the resulting changes. Although the ice cube under the light has not fully melted in 10 minutes, students infer that the heat from the bulb caused the solid, an ice cube, to melt faster than the other ice cube. After the investigation, the teacher shows students how the water can be poured back into the ice cube tray and asks them what will happen when she puts the tray back in the freezer. Students state that when the tray is put in the freezer the water eventually will become solid once again.

Day 6:
The students follow similar procedures to those they used the previous day for the ice cube to investigate wax. Students note that the wax does not melt like the ice cube at room temperature, but the wax melts underneath the hot lamp. The teacher asks, "What happened when we put the ice cube and the wax under the hot lamp?" One student replies, "They melted!" Another states, "They were solids, then they became liquids." The teacher continues, "What happened when we took them away from the lamp?" A student offers, "The wax started to harden again. It was going back to normal." The teacher asked, "Could we get the ice back to normal?" A number of students said, "Yes! Put it in the freezer!"

Day 7–8:
The unit continues with students investigating irreversible changes, such as cooking an egg.

Day 9:
At the conclusion of the unit, students use their data to develop an explanation about the changes they saw over the course of the unit. For example:

> *When you heat or cool something there might be changes that you can see—like when you heat an ice cube it turns to water, when you heat up wax it becomes liquid, or when you cook an egg it gets hard. Sometimes these changes in materials can be changed back, like you can put water back in the freezer. Sometimes you can't change the materials back like when you cook an egg.*

Grades K–2 Cross-Vignette Reflections

This section highlights the instances where grades K–2 students engage with the key elements of each practice in the preceding vignettes. Some key elements can be found in a single vignette while others are illustrated in multiple vignettes.

Practice 1: Asking Questions

The science practice of asking questions is illustrated in the Earth and Space Science (ESS) vignette in this grade band.

Key Elements of Asking Questions in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Distinguish between scientific and non-scientific question		X	
B. Generate scientific questions that arise from curiosity, prior knowledge, careful observation of phenomena, models, or emerging data		X	
C. Construct an appropriate type of scientific question for the purpose of developing scientific knowledge (note: questions may include facets of one or more of these types):		X	
i. Descriptive—Identify and characterize relevant aspects (features, functions, processes) of a phenomenon or system			
ii. Relational—Examine the relationships among relevant aspects (features, functions, processes) of a phenomenon or system			
iii. Causal—Identify whether a relevant aspect (features, functions, processes) of a phenomenon or system affects another and/or the mechanism for that relationship			
D. Refine/revise scientific questions based on observations/data, models, and/or existing scientific knowledge to more clearly focus the question or explore emerging ideas		X	

In this vignette, students generate questions about the weather based on their curiosity (Key Element B) and then refine these questions to focus on how weather changes over time (Key Element C). As part of the process of generating questions, the teacher reminds students that a question is not scientific if it cannot be tested (Key Element A). After beginning data collection students realize that they cannot collect data to answer one of their questions ("How does the number of clouds change from day to day?"), so they revise both their question and data collection strategy (Key Element D).

Practice 2: Developing and Using Models

The science practice of developing and using models is illustrated in the Life Science (LS) vignette in this grade band.

Key Elements of Developing and Using Models in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop an appropriate model that will best serve the intended purposes i. Nature of models: a. Descriptive—Represent and characterize relevant aspects (features, functions, processes) of a phenomenon or system, including those that are not visible to the human eye b. Relational—Illustrate relationships among two or more relevant aspects (features, functions, processes) of a phenomenon or system c. Causal—Illustrate how a relevant aspect (features, functions, processes) of a phenomenon or system affects another and the mechanism for that relationship ii. Purpose of models: a. To communicate to others for the purposes of informing, use as evidence for a claim in an argument, eliciting feedback, etc. b. To make predictions (testable hypotheses) c. To compare with other models d. To improve the understanding and/or accuracy of cause-effect relationships or causal mechanisms for a phenomenon or system	X		
B. Identify the relevant components of the phenomenon/system, relationships among them, and/or potential causal mechanisms to include in the model based on existing scientific knowledge, evidence, and the type/function of the model	X		
C. Identify and evaluate merits and limitations of a model (e.g., accuracy, plausibility, clarity, ability to provide insight into the description/processes/causal aspects of a phenomenon or system)	X		
D. Revise a model based on evidence to improve its accuracy, clarity, complexity, generalizability, accessibility to others, and/or predictive power	X		
E. Compare multiple models to determine merits and limitations of each in relation to relevant factors such as purpose, scientific evidence, intended audience, predictive power, accuracy, and/or generalizability	X		

In the LS vignette, students develop simple models as they draw pictures of plant growth over time via the use of a graphic organizer (a developmentally appropriate method of engaging with Key Element A). They label these drawings, identifying components of the system they are investigating that could impact the health of their plants (e.g., location, amount of water) and ones that indicate how healthy the plants actually are (e.g., color, height) (Key Element B). Students also reflect on their drawings, discussing whether the drawings are clear and accurate (Key Element C). The students in the vignette improve the accuracy, clarity, and complexity of their models over time, adding color and providing additional details based on their ongoing observations (Key Element D). In addition, students compare their drawings to the drawings of other groups, commenting on differences in details and whether those differences make their drawing "more like what they are seeing" in their investigation (Key Element E).

Practice 3: Planning and Carrying out Investigations

The science practice of planning and carrying out investigations is illustrated in both the ESS and Physical Science (PS) vignettes in this grade band.

Key Elements of Planning and Carrying out Investigations in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Identify what evidence is required to answer a scientific question		X	
B. Design different types of investigations (e.g., observational, experimental) to provide valid and reliable data that can be used as evidence to answer different types of scientific questions (e.g., descriptive, relational, causal)		X	
C. Carefully and systematically implement an investigation (e.g., make observations/measurements, manipulate/control variables, record data) consistent with the design of the investigation		X	X
D. Revise the design of an investigation as necessary based on preliminary findings or problems that arise with the initial design and/or procedures		X	

Students carefully and systematically implement investigations in both the ESS and PS vignettes (Key Element C). In the PS vignette, students explore the phenomenon of melting by making detailed observations of ice cubes and wax when they are exposed to heat. In the ESS vignette, students make observations, take measurements, and record data about various facets of weather over multiple days.

In the ESS vignette, students engage with additional elements of planning and carrying out investigations. Students identify what evidence is needed to answer their questions about how weather changes over time (Key Element A), and then determine how to carry out an investigation to collect those data (Key Element B). In addition, students revise their experimental procedure by moving rain gauges to more desirable locations when they realize that their original placement is leading to inaccurate measurements (Key Element D).

Practice 4: Analyzing and Interpreting Data

The science practice of analyzing and interpreting data is illustrated in all three of the vignettes in this grade band.

Key Elements of Analyzing and Interpreting Data in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Construct a data display (tabular, graphical) that facilitates analysis for answering the question being examined	X	X	
B. Systematically compare data from multiple trials or measurements for consistency (within and/or across groups of students) to consider potential sources of error in data collection and/or identify anomalous cases		X	
C. Analyze the data using grade-appropriate mathematical/statistical techniques to identify patterns, trends, and relationships	X	X	
D. Consider the limitations of data (e.g., missing data, measurement error) and the implications for the analysis and interpreting results		X	
E. Interpret (describe the meaning and relevance of) the results of the analyses for the question being examined	X	X	X

The LS and ESS vignettes illustrate how students might construct data displays (Key Element A) and analyze data (Key Element C) using grade-appropriate techniques. Students in the LS vignette use a recording sheet provided by the teacher to document plant height over time. They then look across the plant height measurements collected by the entire class to identify trends. Similarly, in the ESS vignette, students chart temperature data on large pieces of grid paper and then analyze these data to identify patterns.

In all of the K–2 vignettes, students interpret the results of the analyses for the questions being examined (Key Element E). In the PS vignette, students observe that an ice cube under a lamp melts faster than an ice cube that is not under a lamp, and use this result in answering the question of how heat affects the melting rate. In the LS vignette, students determine that their observational data show that plants receiving both sunlight and water are healthier than those that do not. In the ESS vignette, students examine temperature, rainfall, and cloud cover data and conclude that weather changes both within a single day and across multiple days.

Students in the ESS vignette also engage with other key elements of this practice. They compare multiple rain gauge measurements for consistency and consider potential errors in data collection (Key Element B). When measurement errors are found, the students consider what those data might mean in relation to their question about how weather changes over time, and decide not to include the faulty data (Key Element D).

Practice 5: Using Mathematics and Computational Thinking

The science practice of using mathematics and computational thinking is illustrated in two of the vignettes in this grade band.

Key Elements of Using Mathematics and Computational Thinking in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Use mathematics and computational thinking to develop and then use models in order to explore a phenomenon (e.g., determine a mathematical relationship to represent a phenomenon, develop a computational simulation to explore a phenomenon)			
B. Use mathematics and computational thinking in data collection (e.g., create an algorithmic procedure for data collection, determine criteria for sampling cases and programming a computer to identify all cases that meet the criteria)		**X**	
C. Select and use appropriate mathematical/statistical/computational techniques to organize and analyze data (e.g., determining the best measure of central tendency, examining variation in data, developing a fit line, developing rules for organizing data to make patterns evident)	**X**		
D. Use mathematical or computational models to generate evidence to support a claim when constructing explanations or engaging in argument from evidence			

In the ESS vignette, the teacher helps the students come up with procedures for collecting weather data in systematic ways that can be repeated over multiple days (Key Element B). For example, students shade boxes on grid paper to chart temperature and develop rating systems to keep track of cloud cover and wind strength over the course of the unit. In the LS vignette, students use blocks to measure the height of different plants and then compare these measurements across groups (Key Element C).

Practice 6: Constructing Explanations

The science practice of constructing explanations is illustrated in two of the vignettes in this grade band.

Key Elements of Constructing Explanations in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop a line of reasoning using valid, reliable, and sufficient data as evidence, as well as existing scientific knowledge (e.g., ideas, models, theories) to support a claim		X	X
B. Revise explanations based on new evidence and existing scientific knowledge (e.g., ideas, models, theories)		X	X
C. When appropriate, seek out and use multiple sources of evidence to support a claim accounting for similar or sets of phenomena		X	

Both the ESS and PS vignettes illustrate opportunities for students to engage in age-appropriate tasks on the trajectory toward constructing explanations. Students in the PS vignette consider the properties of several different solids and liquids, and use these observations to come up with definitions for those states of matter (Key Element A). When students discover that some small particle solids can be poured, they revise their definition of solids to take this new information into account (Key Element B). Students in the PS vignette also engage in several activities where they observe physical (e.g., melting) and chemical (e.g., cooking an egg) changes, and then use their observations to explain which changes are reversible and which are not (Key Element A).

Students in the ESS vignette use multiple sources of evidence, both their observations of cloud cover and flag movement and measurements of rainfall and temperature, to support their explanations about how the weather changes from day to day (Key Elements A and C). After students presents their work, the class decides that including multiple features of weather and presenting the related data as evidence creates the most convincing argument. Students revise their explanations, citing these additional sources of evidence (Key Element B).

Practice 7: Engaging in Argument from Evidence

The science practice of engaging in argument from evidence is illustrated in all three of the vignettes in this grade band.

Key Elements of Engaging in Argument from Evidence in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
Developing Arguments			
A. Determine what evidence, including pertinent details about design, implementation, analysis, might persuade an audience about a model/explanation	X	X	X
B. Provide, verbally or in writing, a reasoned justification to support or critique a model/explanation using valid, reliable, and sufficient evidence	X	X	X
C. Evaluate and articulate the strengths and weaknesses of competing explanations		X	X
D. Construct a persuasive case (in writing or verbally) for an intended audience for the best model/explanation for a phenomenon	X	X	
Critiquing Arguments			
E. Pose and respond to questions that elicit pertinent details about the important aspects of an argument, including pertinent details about the research design, implementation, analysis, evidence, and reasoning		X	
F. Use scientific reasoning and evidence to critique an argument, communicating this critique verbally and/or in writing		X	
G. When providing a critique of an argument, describe, verbally or in writing, what evidence is needed to further determine the validity of a claim		X	
H. Compare and critique multiple arguments on the same topic for whether they use similar evidence and/or differ in their interpretation of the evidence		X	
I. Respectfully provide and respond to critiques by citing relevant evidence		X	

The practice of engaging in argument from evidence is composed of two parts: developing arguments and critiquing arguments. In all three vignettes in this grade band, students have opportunities to develop arguments. In the ESS vignette, students discuss with a partner what information from their observations they would share with someone in order to help them understand that weather changes from day to day (Key Element A). They verbally defend their claims that weather changes from day to day, using the data they collected as evidence (Key Element B) and discuss limitations of competing explanations (Key Element C). Students then record their arguments using pictures and words (Key Element D).

In addition, the ESS vignette illustrates the different aspects of critiquing arguments. After presenting their written arguments that weather changes over time, students critique one another's arguments and pose questions about both the arguments and evidence used to support them (Key Elements E and F). Students respond to these critiques (Key Element I) and consider what additional information might be needed to support their arguments (Key Element G). In addition, students look across the arguments noting that most classmates only highlighted one feature, such as the change in wind, while a few classmates shared data from all observations (Key Element H).

Practice 8: Obtaining, Evaluating, and Communicating Information

The science practice of obtaining, evaluating, and communicating information is illustrated in the LS and ESS vignettes in this grade band.

Key Elements of Obtaining, Evaluating, and Communicating Information in Grades K–2 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Read and gather information from scientific and technical resources such as books, articles, tables, graphs, models, and community members relevant to the science-related question	X	X	
B. Evaluate the trustworthiness/credibility of one's own work and/or other sources according to their reliability, validity, consistency, logical coherence, lack of bias, and methodological strengths and weaknesses	X	X	
C. Distinguish observations from inference, and claims from evidence in one's own work and/or in other resources	X		
D. Compare and critique information obtained within one's own work and/or across multiple sources	X		
E. Summarize patterns, similarities, and differences in the information obtained from scientific sources	X		
F. Organize information in appropriate formats (e.g., written, multimedia, visual displays) obtained from one's own investigations and/or other sources in order to communicate it to various audiences	X		
G. Produce scientific and technical text and make oral presentations that integrate qualitative and/or quantitative information and appropriate representations, from one's own or others' scientific investigations, in order to clearly communicate the results	X		

In both the LS and ESS vignettes, students gather information related to their science questions (Key Element A). In the ESS vignette, this information comes from a local meteorologist and in the LS vignette the information comes from grade-appropriate texts, online sources, and teacher read-aloud books. Students in both vignettes also evaluate the trustworthiness of the information they gather (Key Element B). Students in the ESS vignette discuss the credibility of the meteorologist's data verses their own, calling attention to the advanced technology available to the meteorologist for collecting weather data. Students in the LS vignette discuss the differences between fiction and non-fiction texts and consider which provides more useable information about plant growth.

Additional key elements of obtaining, evaluating, and communicating information are illustrated in the LS vignette. After several weeks of collecting data on plant growth, the students summarize what they learned. The teacher uses age-appropriate language to help students talk about the difference between what they observed regarding their plant's growth and what they could infer based on those observations (Key Element C). Students further explore plant growth via fiction and non-fiction texts and discuss similarities and differences in the information obtained from these sources (Key Elements D and E). They then use the information from texts and the investigations they carried out to create posters focused on conditions that optimize plant growth (Key Elements F and G).

Grades 3–5 Vignettes

The three vignettes in this section show how students might engage with the key elements of the practices in grades 3–5. In the life science vignette, fifth grade students learn about relationships among organisms in ecosystems and explore how a change can upset the balance of the entire ecosystem. The Earth and space science vignette describes a fourth grade class investigating factors that affect the rate of erosion. The physical science vignette illustrates a third grade class learning about how and when forces act on objects.

3–5 Life Science

A fifth grade class is beginning a unit about interdependent relationships in ecosystems.[6] The purpose of this unit is for students to identify different types of organisms in a particular ecosystem (i.e., consumers, producers, decomposers), and the feeding relationships among them. Students will investigate how changes to biotic and/or abiotic components of an ecosystem affect the balance of the ecosystem, and will use simulation data they collect to develop explanations.

Day 1:

The class begins by reviewing the definition of the term "ecosystem" and students brainstorm different types of ecosystems such as forests, oceans, and deserts. The teacher says that, today, they will be examining a pond ecosystem in their home state of New York. Students divide into groups, each with a digital tablet, and visit a variety of websites to research the components of a New York pond ecosystem and the relationships among them. As the students review the websites, they complete a "notes sheet" listing each piece of information they find, the type of website the information was obtained from (e.g., .edu, .gov, .com), and their assessment of whether the website is a credible source and why. Students look across the information in the websites, noting similarities and differences in what they find. Throughout this process, the teacher provides assistance with evaluating the credibility of the websites, highlighting

[6] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

> **DCI: LS2.A: Interdependent Relationships in Ecosystems**
> The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.
>
> **PE: 5-LS2-1**
> Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment. [Clarification Statement: Emphasis is on the idea that matter that is not food (air, water, decomposed materials in soil) is changed by plants into matter that is food. Examples of systems could include organisms, ecosystems, and the Earth.] [Assessment Boundary: Assessment does not include molecular explanations.]

differences among domains and implications for the trustworthiness of the information contained therein. The class then comes back together to discuss their findings, make a list of the living and nonliving things that could be found in a New York pond ecosystem, and discussing any discrepancies in their findings.

The teacher then reminds the students that they learned about food webs in 4th grade, and asks if they remember what food webs can tell them. Student responses include:

> *A food web shows how all the different living things are related to each other.*

> *A food web shows what eats what in an ecosystem.*

The teacher then gives each student a set of 10 notecards with pictures of organisms that live in a New York pond ecosystem and some plastic arrows. They are told to use the arrows to represent the feeding relationships that they think exist among the organisms on the cards, and write short justifications for each relationship based on their research. After 15 minutes of working on the task, the students then discuss with a partner the food web that they constructed, noting any differences. Students revise their individual food webs as necessary based on their collective research findings, and each pair comes to consensus on a food web that most accurately shows the feeding relationships in the pond ecosystem.

Students work in pairs to assign each organism in their consensus food web to one of three groups they learned about in a previous unit: “producer,” “consumer,” and “decomposer.” As they work, the teacher circulates and prompts them to explain some of the relationships among organisms in their food web. For example, students explain that consumers eat producers and that some consumers eat other consumers. Students then take digital pictures of their models so that they can return to them in the future.

To conclude the lesson, the teacher explains that a food web is a type of model and that models can help them represent things that are often not very easy to see in a classroom. She points out that they did not actually go out and look at a pond ecosystem. Rather, they used pictures of organisms rather than real organisms, and arrows to show what eats what, as it was not realistic for them to see the feeding relationships between different organisms in this pond ecosystem firsthand. The students are asked to think about the strengths and limitations of this type of picture-and-arrows model for depicting the interactions between organisms in an ecosystem. Students suggest that this type of model is easy to create and makes feeding relationships easy to visualize. However, they also note that the model does not include all possible organisms in a pond ecosystem and does not show what happens if the ecosystem changes over time.

Day 2:

Students are each given a tablet again to run a food web simulation. The simulation includes several living components of a pond ecosystem (the same ones the students worked with on Day 1), as well as some nonliving components (e.g., water, salt, dissolved oxygen).

The teacher explains that the simulation shows a stable New York pond ecosystem. She explains that ponds can be stable ecosystems for long periods of time, meaning that many different species can exist in the pond without any of the species dying out. Students are given 15 minutes to explore the simulation and told to make some notes about the populations of producers, consumers, and decomposers over time. Next, they use the simulation to investigate what happens when something in the stable ecosystem changes. The teacher ask students to write down a prediction about what will happen to the largest fish in the ecosystem if the number of frogs steadily decreases over five years, using what they learned yesterday about the feeding relationships in a New York pond ecosystem. Students then share their thinking with a partner. For example:

> *The simulation shows that the pond includes trout. Yesterday when we did research online, I learned that trout are big fish. I also learned that trout eat lots of different things, including frogs. So I think that if there are fewer frogs, there will also be fewer trout over time because they won't have enough to eat and some will die.*

The teacher then shows students how to manipulate the simulation in order to produce data that can help them answer the question. The simulation produces a data table and graph showing the populations of both organisms over five years. Students individually interpret the output and use the data as evidence to make a claim about what happens to the number of large fish. Most students correctly conclude that the number of large fish steadily decreases as the number of frogs decreases. Students compare their claim with a partner, noting any discrepancies. When there are discrepancies, the teacher directs students to seek out reasons for them, including errors in setting up the simulation or differing interpretations of the output. The teacher then leads a class discussion about whether their initial predictions were correct or incorrect based on the evidence from the simulation.

Day 3:
Students once again interact with the food web simulation. With support from the teacher, students decide upon a relationship that they want to investigate within the pond ecosystem. For example, one pair wonders, "What will happen to the small fish over time if a new type of plant comes into the ecosystem?" Because they learned from their research that many types of small fish eat plants, the students predict that the number of small fish will increase because they will have more food. They first use the simulation to look at the population of small fish and the plants that they eat in the stable pond ecosystem after 6 months, 12 months, and 18 months.

Although they see small changes, the populations largely remain constant. They then set up the simulation again, this time introducing a new aquatic plant.

The students work in their groups to develop an explanation for the question they are exploring. For example:

> *The aquatic plant does not affect the population of small fish. The population of fish was about the same before and up to 18 months after the new plants were introduced. Because the number of fish didn't change much, the new plant doesn't impact the fish in this ecosystem.*

The teacher points out that 18 months can be a relatively short period of time for an ecosystem, and asks the students to think about what might happen if they look over a longer time. The students revise their procedure, setting the simulation to look at the number of small fish after 1 year, 2 years, and 3 years. They notice that the small fish start to decrease 3 years after the new plant is introduced. They then set the simulation to look at 5 years, and see a noticeable decline in the number of small fish. The students compare the simulation data from the stable ecosystem to the simulation data from the ecosystem with the new aquatic plant, and revise their explanation:

> *The introduction of a new plant negatively affects the number of small fish. The population of fish was about the same before and up to 18 months. But, after 18 months, the number of fish and original plants decreased. Because the number of fish decreased in a longer timeframe, the new plant does impact the fish in this ecosystem.*

The teacher tells the groups to revisit their initial predictions and discuss whether or not the data from the simulation supported their prediction. Students are then given a set of sentence starters to use in developing an argument to convince someone else about their claim related to the question they were studying. For example:

- The question we investigated was…
- We predicted that…
- Our data showed that…
- Our claim is that…
- Our reason for our claim based on our evidence is…

Next, students present the argument they developed. With the teacher's guidance, students critique each argument, posing questions related to the claims being made and reasoning for how the evidence supports the claims. Students are instructed to choose the one argument they think is best supported by the data and explain their rationale to their partner. The teacher circulates as they work, helping students articulate and expand upon their rationales. For example, one student suggests that an argument is better if it is longer. The teacher helps the student focus instead on the substance of the argument, prompting the student to key in on what pieces of information are used to support each argument. To conclude the lesson, the teacher tells the students to go back to their sentence starters and note the strengths and weaknesses in their own arguments. Students are given the opportunity to revise their arguments as necessary.

Day 4:
The teacher points out to the students that they have used two different types of models for depicting the interactions among organisms in a pond ecosystem, the cards with arrows and the computer simulation. She asks them to talk in small groups about the strengths and limitations of each type for improving our understanding of the relationships in the ecosystem. She then asks groups which type they think is better. With the teacher's guidance, students come to a consensus that the "best" type of model depends on what you want to use the model for and who is going to be using the model but determine for the purpose of understanding the relationships among the organists, the computer simulation is a better.

The teacher notes that different groups investigated different questions, and gives a brief summary of the different investigations. She points out that all of the groups looked at what happened to one part of the ecosystem when another part of the ecosystem changed. She then gives several students the opportunity to explain how the change they observed impacted the ecosystem. For example:

> *We looked at what happened to producers and consumers if the oxygen in the pond decreased by different amounts. We used the simulation to create a graph that shows how the populations of three different organisms changed as the oxygen decreased. Looking at the graph, we know that decreased oxygen was harmful to all three of these organisms, because their numbers went down as the amount oxygen went down. Without the right amount of oxygen, they didn't stay healthy and the ecosystem didn't stay stable. This change to one part of the ecosystem affected big changes to other parts of the ecosystem.*

Another student explains that her group looked at what happened when the temperature of the pond increased. She agrees that changes to one part of an ecosystem affect other parts, but notes that their data showed that increased temperature was beneficial to some organisms. Looking across the different group investigations, the class comes to the consensus that changes to part of an ecosystem can have both positive and negative effects on other parts of the ecosystem.

3–5 Earth and Space Science

Students in a fourth grade class are engaged in a unit on earth materials and systems. Prior to this sequence of lessons, students examined different types of weathering (mechanical, chemical, and biological) caused by liquid water, ice, wind, living organisms, and gravity. Currently, students are exploring changes on Earth by examining factors that affect the rate of erosion in a region.[7] The purpose of this sequence of lessons is for students to collect evidence in order to develop an explanation about what affects the rate of erosion.

Day 1:

The teacher starts the first lesson by showing students illustrations of two different mountains along with the following text:

> *Mountain A is 4,800 feet tall, looks smooth and round, and is located in North America. Mountain B is 19,280 feet tall, looks sharp and jagged, and is located in South America. Both mountains were originally formed by the uplifting of Earth's crust millions of years ago, are composed of similar materials, and are found in similar climate conditions.*

Students are asked to write individually in their journals their thinking about whether one mountain is older than the other (and if so, which one), or if they are the same age. They are also instructed to explain their reasoning for their answer, drawing on information from the illustrations and anything they have observed in their everyday life. After students complete this task, they discuss their responses in small groups with their classmates. The teacher circulates during this discussion and then comments to the group that there are differences in the responses among the students in the class. The teacher informs the students that they are going to do some investigations that might help with their thinking about the "mountain problem."

The teacher divides the students into six groups and asks each to go to a different station in the room. At each station is a stream table, oriented at a 20 degree angle and filled with sand. Each stream table has a water source that can be adjusted to vary the rate of water flow and a collection container to capture water and sand that runs off from the table. The teacher gives the

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[7] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

DCI: ESS2.A: Earth Materials and Systems
Rainfall helps to shape the land and affects the types of living things found in a region. Water, ice, wind, living organisms, and gravity break rocks, soils, and sediments into smaller particles and move them around.

PE: 4-ESS2-1
Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation. [Clarification Statement: Examples of variables to test could include angle of slope in the downhill movement of water, amount of vegetation, speed of wind, relative rate of deposition, cycles of freezing and thawing of water, cycles of heating and cooling, and volume of water flow.] [Assessment Boundary: Assessment is limited to a single form of weathering or erosion.]

students about 10 minutes to move sand around in their stream table and add rocks and "vegetation" to create various landforms such as hills and valleys. After they are finished, students are instructed to draw a picture of their landform in their journal. The student groups are then instructed to set their water flow to the lowest flow setting and observe what happens in their stream table for five minutes and record their observations. Toward the end of the five minutes, the teacher asks the students to draw a picture of the landform after the water flow. In addition, the students are told to take the content of the collection container (sand and water) and pour the water through a strainer and measure the amount of sand using a graduated cylinder, again recording the data. The teacher reminds the students that, when using the graduated cylinder, it is important to make sure that your eyes are level to the graduated marks on the cylinder to ensure that you have an accurate measurement.

The teacher then asks several students to share their observations of what happened as the water was flowing in their stream table. For example, students report, "the water carried the sand into the container," "the water made big grooves in my sand," and "the water went around the big rocks because they didn't move." Students also share the amount of sediment that they collected. The teacher then asks the group, "How did the stream table model change after the water flowed?" A couple of students comment that the hills they made were smaller or that the water made grooves in the sand. The teacher asks questions to focus students on why the hills were smaller and the causes of the grooves they had observed. A number of students point out that the water had carried sand away leading to these changes. The teacher asks the students if they know the term for the process that caused the changes in the stream table model. One student calls out the term "erosion."

Day 2:
The teacher asked the students to briefly describe what they did yesterday, and tells them that they are going to use the stream tables again today to examine how rain affects the surface of Earth. She then asks, "What questions do you have based on what you saw yesterday? Please write your questions in your science journal." Students write questions like "How much water formed the Grand Canyon?" and "Does the type of sand impact how fast the erosion happens?" Once students generate their questions, they move to their groups from the previous day to share their questions with one another. The teacher explains that there are some questions that we can test using experiments (testable or scientific questions) and some questions which we cannot test (non-scientific questions). The teacher also points out that some questions can be tested, but that it is not feasible to do so in a classroom. She asks them to consider their questions and decide which are testable and which are not. The class uses a chart to organize their questions as testable and non-testable and then, as a class, decide which testable questions would not be feasible to examine in their classroom with the materials they have.

The teacher assigns each group one of three questions to investigate, ensuring that two groups are working on each question:

1. How does the steepness of the hill impact the amount of erosion?
2. How does the amount of "rainfall" impact the amount of erosion?
3. Does the amount of vegetation impact the amount of erosion?

Each group completes an investigation design sheet that guides them in listing the factors that are going to stay constant, factors that they are going to vary, and how they plan to vary the relevant factors (i.e., steepness of the hill, amount of water, amount of vegetation). The students also generate a hypothesis for their research question. For example, "If we increase the steepness of the hill, I think the amount of erosion will increase because in our first experiment we saw more sand got moved the longer the water was running. By making the table steeper, more water will run over the table in the same amount of time." There is a brief class discussion about what would be evidence that erosion increased. Students suggest that they would see increased amounts of sand moving and that they would see more sand in the collection container.

Next, each group implements the investigation that they planned. The groups examining how the steepness of the hill impacts erosion conduct three trials with different slopes, and each time carefully reconstruct the landscape for the next trial. The groups investigating water flow conduct three trials using different rates of water flow (low, medium, and high), keeping the angle and landscape constant for all trials. The groups investigating how the amount of vegetation impacts erosion increase the number of plants in the landscape for each trial, keeping the slope and water flow constant. In all groups, students carefully observe and record on their investigation design sheet what happens in their stream table and draw pictures of the resulting landscape for each trial. They also measure the amount of sand deposited in the collection container for each trial.

The groups organize their data into tables using a template provided by the teacher, and look for patterns. In analyzing their data, one group identifies an outlier where they measured very little sand in the collection container. The group notes that they had difficulty measuring the amount of sand deposited on that trial as the tube leading to the collection container got clogged. The teacher encourages the students to repeat the trial in order to have a more accurate measure. Groups are instructed to graph their data and use the graph to predict what would happen if they made the conditions more extreme (e.g., even steeper slopes, even more vegetation), and then conduct these additional trials.

After, students are asked to summarize in their science journals what the data tell them about the question they are trying to answer. Each group is charged with generating a claim about what they found in their investigation, their reasoning for their claim, and, providing evidence to support their reasoning. As the groups work, the teacher circulates and asks students to share their explanations. In one group a student states, “When we increased the angle, the dirt measured was bigger.” The teacher reminds the student that an explanation is their answer to the question that they were exploring, and that it must be supported by evidence and reasoning. The teacher helps guide the students to improve their explanations. For example, a revised explanation is:

> *As the steepness of the hill got bigger there was more erosion. We know this because there was more sand in the collection bucket which means more sand was being moved. We saw that the water moved faster when the hill was steeper and when the water moved faster it took more sand with it.*

The groups also construct diagrams that illustrate the processes at play in their investigations. For example, the group investigating slope draws side views of the stream table at the three different angles, illustrating the speed of the water and the characteristics of the surface after each trial. After, student groups discuss the merits and limitations of their diagrams for describing the relationship between the variables that they were examining, guided by the following questions, “How are the diagrams you drew the same or different from what was actually happening in your stream table? What do your diagrams tell you about what you were investigating? What don’t they tell you about what you were investigating?”

Day 3:
The groups examining different factors are mixed to share what their investigations revealed about factors that affect erosion. Each mixed group creates an expanded explanation to include evidence from all of the investigations. They then organize their work into a PowerPoint presentation, describing their procedures and findings, including why their evidence supports their claim.

Day 4:
Each group takes turns giving their presentation to the rest of the class. After each presentation, students and the teacher write down questions they had about the group’s claim using the following prompts, “Did the group provide evidence that supported their claim? Did their models (diagrams) include all the factors affecting erosion that they talked about? What else would convince you?” After the presentations, each group is given the questions and prepares written responses, providing pertinent evidence when needed.

After the presentations, each group is instructed to consider the original question that they explored and to revise their questions based on what they learned about erosion. For example, one group’s revised question is, “How does the incline of the stream table impact erosion of small sediment (e.g., sand) vs. large sediment (e.g., pebbles)?" Student will explore their questions the next day in class.

Day 5:
After students finish exploring their revised questions, the teacher asks that students to open their journals to where they wrote about the mountain problem. They are asked to review their original response and revise it based on information they learned from conducting their investigations.

3–5 Physical Science

A third grade class is in the middle of a unit about forces and motion. They recently completed a series of lessons centered on understanding changes in motion. They have also learned that a force is a push or pull interaction between two objects. The class is now moving on to a series of lessons in which they will collect evidence in order to develop explanations about when forces act on objects.[8]

Day 1:
The lesson starts with students responding to the following scenario:

> *Imagine a soccer player taking a shot on goal. She runs up and kicks the ball which flies toward the goal, where the goalkeeper catches it. When does the force of her kick stop acting on the ball and why?*

Students discuss this scenario in small groups and then several students share their ideas aloud:

> *Our group thinks the force of the kick stops acting when the goalkeeper catches the ball, because that's when the ball stops moving.*

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[8] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

> **DCI: PS2.A: Forces and Motion**
> Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. (Boundary: Qualitative and conceptual, but not quantitative addition of forces, are used at this level.)
>
> **PE: 3-PS2-1**
> Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.]

> *We think that the force stops acting while the ball is in the air. The force runs out between the kick and the catch.*
>
> *Our group said that the force stops acting as soon as it leaves her foot, because she isn't actually touching it anymore.*

The teacher praises the students for their thoughtful responses and says that they will do an activity that will help them investigate when a force stops acting on an object. Students are divided into pairs and given a toy car with a large square of soft foam attached to the top. They are instructed to give the back edge of the foam several quick pushes to start the car moving and gradually increase its speed. The teacher tells them to pay particular attention to what happens to the foam during and between pushes. He then leads a class discussion about the students' observations:

Teacher:	*Was a force pushing the car forward while your finger was touching the foam?*
Student 1:	*Yes.*
Teacher:	*How do you know?*
Student 1:	*The foam dented in when we pushed it, so there was a force.*
Teacher:	*Ok, so was a force pushing the car forward while your finger was not touching it?*
Student 2:	*Yes, because the car kept going forward.*
Student 3:	*I disagree. The car kept going, but there wasn't a force in between pushes.*
Teacher:	*Why do you say there wasn't a force acting between pushes?*
Student 3:	*Because the foam was only dented in when we were pushing on it.*
Student 4:	*Also, it looked like the car sped up when we pushed it and the foam was dented, but didn't speed up when the foam wasn't dented.*

The teacher suggests that the students consider the foam to be a "force detector." He asks what a change in the shape of the foam indicates, and most students agree that when the foam is dented it means that a force is acting. After further discussing the changes they observed in the foam and the car's motion, the class comes to the consensus that there was a force acting on the car when they were in contact with the foam, but not when there was no contact.

The teacher then asks the students to reconsider the soccer ball scenario. Students once again discuss the scenario in small groups. All groups indicate that the force stops acting on the soccer ball as soon as it leaves the soccer player's foot.

Day 2:
The teacher reminds students that they previously applied a force to a toy car by touching it with their fingers. He says that today they will be investigating whether objects can apply forces without touching each other.

Students are divided into groups and each group is given several metal paperclips and posed with the question, "Can you make the paperclips move without touching them?" In small group discussions, students suggest such things as blowing on them, tilting the desk, and using a magnet. The groups are then given a magnet and instructed to slowly and carefully slide the magnet towards one paperclip and observe what happens. Students carry out the activity and note that when the magnet is a few centimeters from the paperclip, the paperclip quickly moves towards the magnet and eventually touches it. The teacher asks if the magnet applied a force to the paperclip before they touched each other. Most students agree that it did, and one explains:

> *The magnet applied a force before they were touching because it made the paperclip move. The paperclip jumped over and stuck to the magnet when they got close together.*

The groups are then given a balloon and some small pieces of shredded paper. The teacher asks the students to rub the balloon on someone's shirt or sweater, and then bring the rubbed side of the balloon near the shredded paper on the table. Students carry out the activity and see the pieces of paper lift off the table and stick to the balloon. The teacher asks the groups what they thought was going on with the balloon and paper pieces. All students agree that the balloon applied a force to the paper before they touched each other, citing the movement of the pieces of paper towards the balloon as evidence.

To conclude the lesson, students are given the following writing prompt, "Can some objects apply forces to other objects without touching them? How do you know?" He tells the students that their response to the prompt is a claim, and that they should include evidence and reasoning for how the evidence supports the claim. Students then share their thinking in small groups. As they discuss, the teacher circulates to help them evaluate whether their claims are supported by reasoning and evidence. For example:

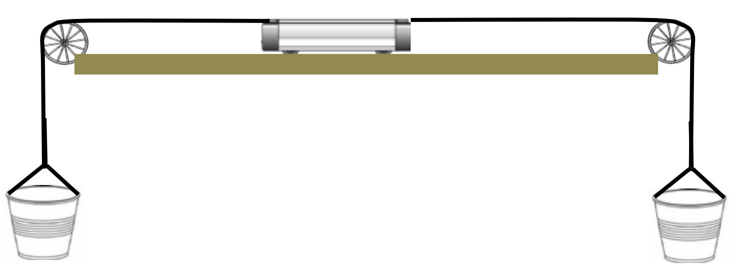
Student 1:	*Some objects can apply forces without touching other objects as long as they are pretty close together.*
Teacher:	*Is that a complete response?*
Student 2:	*I think that is a good claim, but there is no evidence. You should talk about the paperclip or the balloon and use those as evidence. Like when the magnet was close to the paperclip, but not touching it, it made the paperclip start moving.*

The students evaluate the strengths and weaknesses of the various explanations. Some students refute claims made by their classmates that are not supported by reasoning and evidence, e.g., from the paperclip and balloon activities.

Day 3:
The teacher reminds the students that so far they have looked at the effect of a single force on the motion of an object. He tells them that today they will investigate what happens when more than one force acts on an object at the same time.

The class moves into the hallway and sets up a tug-of-war competition, with half of the students on each side of a long rope. When given the signal, the students begin to pull on the rope. At first, the rope doesn't move. The teacher stops the students and asks what is happening. One student states that both sides are pulling with the same strength so the rope is not moving. Another student comments that the pulling was "balancing out." The teacher affirms the student explaining that when equal strength forces act on an object in opposite directions the forces are balanced. The tug-of-war resumes; slowly the rope begins moving in the direction of one team. The teacher stops the contest a second time and asks the group to describe what is happening now. One student indicates the rope started moving towards team that was pulling harder and the group agrees that the forces are unbalanced.

The teacher says that they will continue to investigate balanced and unbalanced forces. A low-friction cart is set up on a track. A string is tied to each end of the cart and these strings pass over pulleys at each end of the track. A cup hangs from each end of the string. The teacher explains that he will be adding sugar cubes to the cups, which causes a force to be applied to the string—the string will apply a force to the cart and that the cart will be free to move once it is released.



Each student has a data sheet for recording information about each trial of the experiment, including the numbers of sugar cubes in each cup and the direction the cart starts to move. The teacher starts by putting two sugar cubes in each cup while holding the cart steady. He asks the students to write down their prediction about whether the cart will start to move when it is released and in which direction, using what they learned from the tug-of-war activity to support their prediction. For example, a student writes:

> *I don't think the cart will move in either direction because there are the same numbers of sugar cubes in both cups, so strength of the forces acting on both sides is equal and balanced. We saw the same thing during the first part of the tug-of-war. When the pulling on both sides of the rope was balanced, the rope didn't move.*

The teacher then releases the cart and the students see that it does not move.

Next, the teacher puts five sugar cubes in one cup and three sugar cubes in the other cup while holding the cart steady. He once again has students write down their predictions about whether the cart will start to move when it is released and in which direction, drawing on prior experiences to support these predictions. He then releases the cart and, as most students predicted, it starts to move towards the side with more sugar cubes. The teacher follows the same procedure for several additional combinations of sugar cubes. He then explains the concept of net force and helps the students use their data to calculate the net force for each of the trials. Students look for patterns across trials related to the behavior of the cart and the net force.

Students examine their data, looking across multiple trials to see if there were any instances where the cart did not start to move in the direction they expected it would. Students agree that the motion of the cart was as expected in all trials. To end the lesson, the teacher shares two answers to the question, "When we did tests where the numbers of sugar cubes in the two cups were not equal, were the forces acting on the cart balanced or unbalanced, and how do you know?"

> Answer 1: *The forces were balanced because both sides of the cart had some sugar cubes pulling on it. It doesn't matter how many sugar cubes there are, it is still a force. So because forces were acting on both sides of the cart, the forces were balanced.*
>
> Answer 2: *The forces were unbalanced because the cup with more sugar cubes applied more force on the cart. That is why the cart started to move in the direction of the cup with more sugar cubes.*

Students are asked to use their observations of the low-friction cart trials to develop an argument for which response is the best and why.

Day 4:

To conclude the unit, the teacher asks the students to think about all of the activities they have completed over the past few days. She divides them into groups and instructs them to use observational data to support their answers the following questions:

1. What effect does a force have on the motion of an object? How do you know?
2. Does one object have to touch another object to apply a force? How do you know?
3. How might you be able to determine whether the forces acting on an object were balanced or unbalanced?

Cross-Vignette Reflection: Grades 3–5

This section highlights the instances where grades 3–5 students engage with the key elements of each practice in the preceding vignettes. Some key elements can be found in a single vignette while others play out in multiple vignettes.

Practice 1: Asking Questions

The science practice of asking questions is illustrated in two of the vignettes in this grade band.

Key Elements of Asking Questions in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Distinguish between scientific and non-scientific question		X	
B. Generate scientific questions that arise from curiosity, prior knowledge, careful observation of phenomena, models, or emerging data	X	X	
C. Construct an appropriate type of scientific question for the purpose of developing scientific knowledge (note: questions may include facets of one or more of these types):	X		
i. Descriptive—Identify and characterize relevant aspects (features, functions, processes) of a phenomenon or system.			
ii. Relational—Examine the relationships among relevant aspects (features, functions, processes) of a phenomenon or system			
iii. Causal—Identify whether a relevant aspect (features, functions, processes) of a phenomenon or system affects another and/or the mechanism for that relationship			
D. Refine/revise scientific questions based on observations/data, models, and/or existing scientific knowledge to more clearly focus the question or explore emerging ideas		X	

In the ESS vignette, students generate questions about how water flow affects the surface of Earth based on their stream table observations (Key Element B). The teacher also supports students' distinguishing between scientific and non-scientific questions, asking them to consider which of their questions are testable and which are not (Key Element A). In addition, students revise their initial questions based on what they learned in their investigations about erosion (Key Element D).

In the LS vignette, students identify relationships within a pond ecosystem that they can investigate using a computer simulation. The students generate questions focused on how a change to one part of an ecosystem, such as the introduction of a new species, impacts another part of an ecosystem (Key Element C). Although the teacher provides guidance in crafting the questions, the questions ultimately arise from the students' curiosity and prior knowledge about how various types of changes affect stable ecosystems (Key Element B).

Practice 2: Developing and Using Models

The science practice of developing and using models is illustrated in two of the vignettes in this grade band.

Key Elements of Developing and Using Models in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop an appropriate model that will best serve the intended purposes i. Nature of models: a. Descriptive—Represent and characterize relevant aspects (features, functions, processes) of a phenomenon or system, including those that are not visible to the human eye b. Relational—Illustrate relationships among two or more relevant aspects (features, functions, processes) of a phenomenon or system c. Causal—Illustrate how a relevant aspect (features, functions, processes) of a phenomenon or system affects another and the mechanism for that relationship ii. Purpose of models: a. To communicate to others for the purposes of informing, use as evidence for a claim in an argument, eliciting feedback, etc. b. To make predictions (testable hypotheses) c. To compare with other models d. To improve the understanding and/or accuracy of cause-effect relationships or causal mechanisms for a phenomenon or system	X	X	
B. Identify the relevant components of the phenomenon/system, relationships among them, and/or potential causal mechanisms to include in the model based on existing scientific knowledge, evidence, and the type/function of the model	X	X	
C. Identify and evaluate merits and limitations of a model (e.g., accuracy, plausibility, clarity, ability to provide insight into the description/processes/causal aspects of a phenomenon or system)	X	X	
D. Revise a model based on evidence to improve its accuracy, clarity, complexity, generalizability, accessibility to others, and/or predictive power	X		
E. Compare multiple models to determine merits and limitations of each in relation to relevant factors such as purpose, scientific evidence, intended audience, predictive power, accuracy, and/or generalizability	X		

Students have two opportunities to engage in modeling as they examine interdependent relationships in ecosystems in the LS vignette. Students are first given notecards and plastic arrows and asked to create initial food webs, based on their research, that illustrate feeding relationships among organisms in a New York pond ecosystem (Key Element B). Students then collaboratively revise these initial models, based on their collective research findings, to improve their accuracy (Key Element D). Students consider the strengths and limitations of the notecard and arrow models for depicting interactions between organisms in an ecosystem (Key Element

C). In addition, the students compare two different types of models (notecard/arrows and computer simulations), recognizing that the “best” type of model depends on its intended purpose and audience (Key Element E).

In the ESS vignette, students investigate erosion using a stream table (which serves as a physical model of a landscape and of the process of erosion): hill steepness, amount of water, or amount of vegetation. Students then diagram the relevant components of the stream table (e.g., slope, speed of water, amount of runoff) and relationships among them (Key Element B). Students also discuss the strengths and limitations of their diagrams for describing the relationship between the variables that they were examining (Key Element C).

Although students in these two vignettes are not determining which type of model will best serve the intended purposes (i.e., the models are specified for them), they are introduced to different types of models which they use for multiple purposes, a necessary and grade-appropriate way to engage with Key Element A.

Practice 3: Planning and Carrying out Investigations

The science practice of planning and carrying out investigations is illustrated in all three of the vignettes in this grade band.

Key Elements of Planning and Carrying out Investigations in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Identify what evidence is required to answer a scientific question		X	
B. Design different types of investigations (e.g., observational, experimental) to provide valid and reliable data that can be used as evidence to answer different types of scientific questions (e.g., descriptive, relational, causal)		X	
C. Carefully and systematically implement an investigation (e.g., make observations/measurements, manipulate/control variables, record data) consistent with the design of the investigation	X	X	X
D. Revise the design of an investigation as necessary based on preliminary findings or problems that arise with the initial design and/or procedures	X		

All three vignettes in this grade band illustrate opportunities for students to carefully and systematically implement investigations (Key Element C). In the LS vignette, students manipulate/control variables using a computer simulation in order to produce useful data about the effects of changes to a stable pond ecosystem. In the ESS vignette, students conduct a series of experimental trials using a stream table, and use an organizer provided by the teacher to record their data. Students in the PS vignette carefully follow sets of procedures involving magnets and balloons to investigate whether objects can apply forces without touching each other, and to record their observations.

Additional key elements of planning and carrying out investigations are demonstrated in the LS and ES vignettes. In the LS vignette, a group of students considers ways they might revise their investigation when preliminary results do not show any substantial changes to the ecosystem when a new species in introduced (Key Element D). In the ESS vignette, students design investigations to provide data that can be used to answer their assigned research questions (Key Element B). As part of this process, students consider what would be evidence from their investigation that erosion increased (Key Element A).

Practice 4: Analyzing and Interpreting Data

The science practice of analyzing and interpreting data is illustrated in two of the vignettes in this grade band.

Key Elements of Analyzing and Interpreting Data in Grades 3–5 Vignettes

	Life Science	**Earth and Space Science**	**Physical Science**
A. Construct a data display (tabular, graphical) that facilitates analysis for answering the question being examined		X	X
B. Systematically compare data from multiple trials or measurements for consistency (within and/or across groups of students) to consider potential sources of error in data collection and/or identify anomalous cases			X
C. Analyze the data using grade-appropriate mathematical/statistical techniques to identify patterns, trends, and relationships			X
D. Consider the limitations of data (e.g., missing data, measurement error) and the implications for the analysis and interpreting results		X	
E. Interpret (describe the meaning and relevance of) the results of the analyses for the question being examined		X	X

In both the ESS and PS vignettes, students construct data displays using recording sheets/ templates provided by the teacher (Key Element A) and later use these data to answer their questions. In the PS vignette students also calculate net force for each trial of a cart and look for patterns across the trials related to the behavior of the cart and the net force (Key Element C). These activities allow students to organize/analyze data in ways that facilitates interpretation.

Students in the ESS and PS vignettes then interpret the results of analyses for the questions they are examining (Key Element E). Students in the ESS vignette summarize in writing what the data from the stream table investigations tell them about their assigned questions. Similarly, students in the PS vignette interpret data from several trials of a low-friction cart to determine whether the forces acting on the cart were balanced or unbalanced when the numbers of sugar cubes were not equal.

The vignettes also highlight instances where teachers help their students to be critical consumers of data. For example, students in the ESS vignette are prompted to consider the limitations of their data, with one group repeating one of their experimental trials because they had difficulty accurately measuring the amount of sand run-off from their stream table (Key Element D). Students in the PS vignette examine data from multiple trials of a low-friction cart, looking for instances where the cart did not move in the direction that was expected (Key Element B).

Practice 5: Using Mathematics and Computational Thinking

The science practice of using mathematics and computational thinking is illustrated in two of the vignettes in this grade band.

Key Elements of Using Mathematics and Computational Thinking in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Use mathematics and computational thinking to develop and then use models in order to explore a phenomenon (e.g., determine a mathematical relationship to represent a phenomenon, develop a computational simulation to explore a phenomenon)		X	
B. Use mathematics and computational thinking in data collection (e.g., create an algorithmic procedure for data collection, determine criteria for sampling cases and programming a computer to identify all cases that meet the criteria)			
C. Select and use appropriate mathematical/statistical/computational techniques to organize and analyze data (e.g., determining the best measure of central tendency, examining variation in data, developing a fit line, developing rules for organizing data to make patterns evident)			
D. Use mathematical or computational models to generate evidence to support a claim when constructing explanations or engaging in argument from evidence	**X**		

In the ESS vignette, students design and conduct experiments to investigate how various factors (hill steepness, rainfall, and vegetation) impact the amount of erosion. They then graph their data and use the graphs (a type of model) to make predictions about the amount of erosion under other conditions (Key Element A). Students in the LS vignette use a computer simulation that models interactions in an ecosystem to produce data that they use as evidence to support their claims about what happens to the large fish in a pond ecosystem if the frogs in that ecosystem steadily decrease over several years (Key Element D).

Practice 6: Constructing Explanations

The science practice of constructing explanations is illustrated in all three of the vignettes in this grade band.

Key Elements of Constructing Explanations in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop a line of reasoning using valid, reliable, and sufficient data as evidence, as well as existing scientific knowledge (e.g., ideas, models, theories) to support a claim	X	X	X
B. Revise explanations based on new evidence and existing scientific knowledge (e.g., ideas, models, theories)	X		
C. When appropriate, seek out and use multiple sources of evidence to support a claim accounting for similar or sets of phenomena		X	

At the heart of constructing explanations is the ability of students to develop a line of reasoning using data as evidence to support a claim (Key Element A). This key element is included in all three of the vignettes at this grade range. In the LS vignette, students use data from a simulation to support the claim that when one part of an ecosystem changes, other parts change too; noting that this change can be positive for some organisms and negative for others. In the PS vignette, the teacher presents students with a writing prompt that requires them to make and support a claim, using reasoning and evidence from their investigations with magnets and balloons, about whether objects can apply forces to other objects without touching them. In the ESS vignette, students generate explanations about what they found in their group stream table investigations, using evidence to support their reasoning. Students in the ESS vignette also expand their explanations, using evidence from their classmates' investigations to support their claims about factors that affect erosion (Key Element C).

The LS vignette also illustrates how student might revise explanations based on new evidence (Key Element B). Based on their initial data, the students in this vignette conclude that a new plant does not affect the small fish in a pond ecosystem. However, at the teacher's urging, the students broaden their investigation to a longer timeframe. The additional data causes them to alter their initial explanation, noting that the introduction of a new plant does not affect the number of small fish in the short term, but has a negative effect on them in the long term.

Practice 7: Engaging in Argument from Evidence

The science practice of engaging in argument from evidence is illustrated in all three of the vignettes in this grade band.

Key Elements of Engaging in Argument from Evidence in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
Developing Arguments			
A. Determine what evidence, including pertinent details about design, implementation, analysis, might persuade an audience about a model/explanation	X	X	
B. Provide, verbally or in writing, a reasoned justification to support or critique a model/explanation using valid, reliable, and sufficient evidence	X	X	X
C. Evaluate and articulate the strengths and weaknesses of competing models/explanations			X
D. Construct a persuasive case (in writing or verbally) for an intended audience for the best model/explanation for a phenomenon	X	X	X
Critiquing Arguments			
E. Pose and respond to questions that elicit pertinent details about the important aspects of an argument, including pertinent details about the research design, implementation, analysis, evidence, and reasoning	X	X	
F. Use scientific reasoning and evidence to critique an argument, communicating this critique verbally and/or in writing	X	X	X
G. When providing a critique of an argument, describe, verbally or in writing, what evidence is needed to further determine the validity of a claim		X	
H. Compare and critique multiple arguments on the same topic for whether they use similar evidence and/or differ in their interpretation of the evidence	X		
I. Respectfully provide and respond to critiques by citing relevant evidence		X	

As noted previously, the practice of engaging in argument from evidence is composed of two parts: developing arguments and critiquing arguments. Across all three vignettes in this grade band, students have opportunities to develop arguments. Students in the LS vignette are provided with sentence starters that help them determine what evidence might persuade an audience about a claim (Key Element A), use that evidence to defend a claim in response to alternate claims (Key Element B), and ultimately construct a case for the best explanation for a phenomenon (Key Element D). Students also engage with these three key elements of argumentation in the ESS vignette as they develop PowerPoint presentations that describe their stream table experimental procedures, findings, and how their evidence supports their claims. In the PS vignette, the teacher helps students evaluate the strengths and weaknesses of various explanations (Key Element C), and refute classmates' claims not supported by evidence (Key Element B). The teacher also provides students with a pair of sample explanations for whether or not forces acting on the cart in their experiment were balanced, and has them develop and argument for which is the best and why (Key Element D).

All three vignettes include instances where students critique arguments and communicate the critique verbally or in writing (Key Element F). With the teacher's guidance, students in the LS vignette also pose questions about important aspects of provided arguments related to a stable pond ecosystem (Key Element E) and compare multiple arguments on this same topic to determine which is best supported by the data (Key Element H). In the ESS vignette, the teacher prompts students to generate questions about one another's presentations (Key Elements E and F), noting what additional evidence would be needed to support their claims (Key Element G). Each group is then given the questions generated by others and prepares written responses (Key Element I).

Practice 8: Obtaining, Evaluating, and Communicating Information

The science practice of obtaining, evaluating, and communicating information is illustrated in all three of the vignettes in this grade band.

Key Elements of Obtaining, Evaluating, and Communicating Information in Grades 3–5 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Read and gather information from scientific and technical resources such as books, articles, tables, graphs, models, and community members relevant to the science-related question	X		
B. Evaluate the trustworthiness/credibility of one's own work and/or other sources according to their reliability, validity, consistency, logical coherence, lack of bias, and methodological strengths and weaknesses	X		
C. Distinguish observations from inference, and claims from evidence in one's own work and/or in other resources			X
D. Compare and critique information obtained within one's own work and/or across multiple sources	X		
E. Summarize patterns, similarities, and differences in the information obtained from scientific sources	X		
F. Organize information in appropriate formats (e.g., written, multimedia, visual displays) obtained from one's own investigations and/or other sources in order to communicate it to various audiences		X	
G. Produce scientific and technical text and make oral presentations that integrate qualitative and/or quantitative information and appropriate representations, from one's own or others' scientific investigations, in order to clearly communicate the results		X	

In the LS vignette, the teacher has students visit websites to research the components of a New York pond ecosystem and relationships among them (Key Element A). As students conduct this research, the teacher provides assistance with evaluating the credibility of the websites, highlighting differences among domains and what they mean for the trustworthiness of information contained therein (Key Elements B and D). The teacher also provides students with a "notes sheet," which the students use to review each website noting similarities and differences in the information provided (Key Element E).

Students in the ESS vignette organize their findings from their stream table investigations and develop presentations to communicate to other students in the class factors that they found that affect erosion (Key Elements F and G). In the PS vignette, the teacher helps students distinguish between claims and evidence. Students then use this information to determine whether the claims they are making are supported by evidence (Key Element C).

Grades 6–8 Vignettes

This section includes three vignettes that illustrate how students might engage with the key elements of the practices in grades 6–8. The life science vignette describes an eighth grade class learning about how organs, tissues, and cells work together in organ systems, and how interactions among these organ systems affect the functioning of the human body. The Earth and space science vignette depicts a seventh grade class investigating the causes for the pattern of moon phases. In the physical science vignette, a sixth grade class explores the structure and properties of matter, with particular emphasis on the effects of temperature on states of matter.

6–8 Life Science

An eighth grade class is continuing their unit on the structures and processes of organisms. Students previously engaged with the concept that living things are made of cells, ranging from single-cell organisms to those made up of many different numbers and/or types of cells. In addition, they learned the function of cells: cells take in nutrients from food, convert those nutrients into energy, and then they carry out specialized functions. They also learned the parts of the cells that contribute to the function of the whole cell. The goal for this part of the unit is for students to develop explanations about how organs, tissues, and cells work in each organ system and how the organ systems interact for the function of the human body.[9]

Day 1:

To introduce the topic, the teacher holds up an apple. She asks the students, "If I ate this apple, what body parts would I use?" The students begin to discuss all the body parts it would take to eat the apple. The discussion starts with how the teacher needs to bite the apple, then chew it, then swallow it and then some students comment that the apple also needs to be digested. As the students discuss, the teacher is recording their comments about which body parts bite, chew, swallow, and digest.

The teacher then asks the students, in pairs, to describe how the different body parts work together. Many students immediately think about the mouth and how the teeth bite and then the

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[9] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

> **DCI: LS1.A: Structure and Function**
> In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions.
>
> **PE: MS-LS1-3**
> Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells. [Clarification Statement: Emphasis is on the conceptual understanding that cells form tissues and tissues form organs specialized for particular body functions. Examples could include the interaction of subsystems within a system and the normal functioning of those systems.] [Assessment does not include the mechanism of one body system independent of others. Assessment is limited to the circulatory, excretory, digestive, respiratory, muscular, and nervous systems.

tongue helps with chewing. The teacher presses the students to think what happens to the apple past the mouth. Some pairs begin to discuss how chewing the apple into smaller pieces allows the apple to be swallowed. This idea leads to how swallowing the apple allows it to be digested.

As the students come back together to discuss what they found, one pair poses a question that was bothering them:

> *What happens if one of the parts is missing? Like if someone doesn't have any teeth?*

The whole class begins to discuss this scenario. They decide that if the teacher could not chew, than the other parts of the system would not be able to do their jobs.

One student mentions if the teacher could not chew, then the teacher also could not swallow—the pieces of the apple would be too big. This discussion leads to the students deciding that all the body parts have to be present and working correctly for the apple to be eaten and digested. This claim leads the teacher introducing students to the term system: when a number of different parts work together to make something happen or function.

Students are told to describe in writing other systems they know of outside of the body. They choose various things such as a bikes, schools, and cars, listing all of the parts that work together for it to function. Once they have finished this task, the teacher mentions that the body has multiple systems. Then, she uses a series of pictures to show students a generic breakdown of an organ system. She explains that each organ system is made of different organs, which are made up of different tissues and cells. They are going to have the opportunity to explore these systems over the next few days.

Day 2:
The class begins with the students summarizing what the class talked about the previous day. One student provides her reflection, "So all these systems are made up of organs, which are made up of tissues and cells, that come together to create the system." The rest of the students agree. Then, the teacher tells the students that humans have 12 different organ systems but in this assignment they are only going to look at 6 of the 12 systems.

The students are divided into six groups and each group is assigned a different system: circulatory, excretory, digestive, respiratory, muscular, and nervous. The teacher asks the students to take a few minutes with their groups to decide what kind of questions they should ask in order to learn more about their organ system. Each group begins discussing the questions they have. One group decides they want to know what organs are in the muscular system. Another group gets the digestive system and wants to know what kinds of tissues and cells are a part of the stomach.

The groups come back together and share their questions. One group says that they want to answer the question, "What is the best organ in the digestive system?" The teacher asks them to consider what constitutes a scientific question and whether the question they posed would be considered a scientific question. The class decides the question is not a scientific question because they could not test it. Once a scientific question has been defined, the students further refine the questions they developed. After a few minutes, the entire class decides on two questions each group will answer about their organ system:

1. What organs, tissues, and cells are parts of my organ system?
2. How does each organ contribute to the organ system?

Days 3–4:
The class reviews their questions for their organ systems from the previous day. They then begin to individually research the questions about their organ system by reading and gathering information from multiple types of resources such as books or articles.

After completing research individually, student working on the same system come together to discuss what they found. Some students describe how they researched the organ system by saying that they started with the textbook to try to answer the questions and then they moved to online resources. As the students describe their findings, the teacher asks them to discuss the trustworthiness of each finding based on the nature and reliability of the source, and how it relates to other findings. One group begins to discuss how a medical journal article about the excretory system is likely more reliable than a Wikipedia page. After the students have compared and critiqued the information they individually obtained through their research, they begin to summarize their findings as a group noting both similarities and differences.

The teacher indicates that each group should work together to develop responses to the questions (claims), as well as reasoning for how the information they collected (evidence) supports their responses. As part of this activity, the teacher helps the students distinguish between claims and evidence. Some of the students have printed out visuals of the organ system on the body and others have pictures of individual organs and their tissues and cells. As the students discuss their answers, they create a table including pictures of their organ system.

Days 5–7:
The teacher asks the students to create a color drawing on a large sheet of white butcher paper of the entire organ system they were assigned. As the students are working on the drawings, the teacher walks around and reminds them to answer both questions—the types of organs, tissues, and cells and the function of the organs in the organ system. She also tells the students to be prepared to share their drawing and results with the rest of the class.

Day 8:
The groups come together and begin to present to other groups their explanations for the question, "How does each organ contribute to the organ system?" As each group presents, the other students record that group's findings. During the presentations, a few students comment about organs that are mentioned as having a function in multiple systems. After every group presents their findings, the students take the last few minutes of class to talk with their group about other organ systems that contain the same organs of their organ system. Students begin to see that there is some overlap among organ systems.

Day 9:
The teacher leads a discussion about which groups found parts of their organ system in other organ systems. Students in the respiratory system group indicate that the mouth was mentioned in the digestive system and that the nose was mentioned in the nervous system. Similarly, students point out that the heart (made of up cardiac muscle tissue) is part of both the muscular and circulatory systems. Students come to realize that they need to expand upon their original questions, noting that neither of their original questions dealt with connections among systems. The teacher asks the students to discuss what other questions they would add. After a few minutes of discussion, the class comes back together and decides two questions should be added to their initial research questions:

1. Does my organ system interact with other systems? If so, how?
2. What is the role of my organ system for the function of the entire body system?

After the students add these questions, one student states that he does not know enough about the other organ systems to answer the new questions, and many other students echo this sentiment. To solve the problem, the teacher has the students form new groups. Each new group contains one person from each original group who can serve as an expert on that organ system.

Day 10:
Once the students are in their new groups, the teacher challenges them to explain how their organ system works with the other organ systems, and what role each organ system plays in the functioning of the entire body system. The teacher asks each group to create a diagram showing the connections among all the organ systems. The students use their notes from the previous days and refer to the butcher paper drawings of each organ system posted around the room. The students revise their explanations from the previous days using information from the other organ systems, realizing the interdependency of the organ systems. For example, one group explains how the digestive system interacts with the excretory system:

> *The digestive system interacts with the excretory system to take in nutrients and get rid of waste. The digestive system breaks down food into small particles so nutrients diffuse into the cells more easily. The digestive system also produces waste. The excretory system gets rid of waste. Both systems contain the liver as an organ and neither system could work properly without the other. If the excretory system did not get rid of the waste, then the digestive system could not do its job. If the digestive system did not properly break down food, then the excretory would get rid of all products rather than just the waste.*

After the students develop their explanations about how the organ systems work together and contribute to the function of the body, the teacher asks each group to share their findings and explanations. Each group explains how the organ systems contribute to the function of the body. As each group presents, new connections are found and explained. The students begin to realize that the connections between the organ systems and how they contribute to one another are even more complicated and connected then they initially imagined.

When all the presentations are finished, the students decide that all the systems are important for the body to function as a whole, and are able to provide many reasons and examples why.

6–8 Earth and Space Science

As part of a larger unit focused on the Earth-Sun-Moon system, a seventh grade class spends a week investigating the pattern of moon phases. The learning target for this portion of the unit is for students develop a model to represent and understand the cause and predictable pattern of moon phases.[10]

Day 1:

To introduce the topic, the teacher prompts students to write anything they have observed, heard, or read about the Moon. Students then share one of their ideas aloud (e.g., the Moon does not always have the same shape, people walked on the Moon, the Moon is smaller than Earth).

Day 2:

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[10] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

> **DCI: ESS1.A: The Universe and Its Stars**
> Patterns of the apparent motion of the Sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
>
> **PE: MS-ESS1-1**
> Develop and use a model of the Earth-Sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.]

Students discuss with a partner whether the Moon looks the same every night, and come to the consensus that the Moon takes many different shapes, ranging from a small crescent to a full circle. The teacher explains that the Moon has several different "phases" and that they are going to be working to understand the pattern of these phases and what causes them.

Eight photographs of moon phases are displayed, in random order, on the interactive whiteboard. The teacher tells students:

> *Last month, I took these eight photographs of the Moon on different days of the month. I watched the same location in the sky, waited until the Moon was above the trees, and then took the picture. When the pictures were printed, they were mixed up and the order of observations was lost. I would like to create a moon journal that shows the observations over time, so we need to place the pictures in the correct order and bind them together in a book.*

A set of moon phase photos are distributed to each student, with the teacher noting that the photographs are observational data. She asks them to sort the cards in the order one would expect to see them over the course of a month, starting from a new (all dark) moon. Students work independently at first, and then have the opportunity to compare and discuss sequences with others and make changes to their own sequence. The teacher circulates, asking questions such as, "Why did you decide to place the cards in this order?" or "What were you thinking about when you decided to move that card?"

The teacher tells students that it takes a little over 29 days for the Moon to go through all of its phases. Rather than directly observing the Moon each night to see if their sequence is correct, the students look at an online database of moon phase images over time. Students correct their sequence of moon photos and label each moon phase. The teacher emphasizes that their purpose for using these terms is to ensure clear communication moving forward. The students staple their photos together in order, and the teacher asks them to continue to bring these "moon journals" to class each day as a reference.

Day 3:
The teacher begins the class session by telling the students that some Inuit people explain the existence of the sun and moon in the following way:

> *Anningan, the Moon god, and his sister Malina, the Sun goddess, got into a fight. Malina ran away across the sky so Annigan went searching for her. As Annigan searches for his sister, he forgets to eat and gets thinner and thinner, which explains the crescent moon phases. After disappearing for three days each month to eat, he returns full to start his search all over again.*

The teacher then asks students, "Do you believe this story is true? Why or why not? If not, what do you think causes the moon phases?" Students disagree with this myth and offer alternative ideas including Earth casting a shadow on the Moon, other planets casting a shadow on the Moon, and clouds covering parts of the Moon. The teacher tells students that they will work in small teams to develop a model that represents an explanation for the cause of the moon phases. The teacher engages students in an interactive demonstration using a Styrofoam ball (a pencil is inserted into the ball to ease handling) and a flashlight to model how Earth's rotation causes day and night. Materials are arranged on a table: Styrofoam balls of two sizes, pencils, and flashlights. Each group uses the flashlight to represent the Sun and the pencils as sticks to make the Styrofoam balls representing the Earth and Moon easier to handle.

One group sets up the simulation in the following way: one student holds the flashlight, one holds Earth, and one moves the Moon in a circle around Earth. The student holding Earth positions herself to be at eye level with the "Moon" in order to see the phases as seen from Earth. As the students work, the teacher circulates, asking students questions such as "What part of the Moon do you see lit up when it is in this position?" and "How does what you are seeing compare to the order of moon phases in your moon journal?" After working for 20 minutes to develop an initial model, students use a tablet to film their model in action. A student uploads each video to their class website.

Day 4:
Students work in their groups from the previous day to view the video of their classmates' models. Using commenting capabilities on the class website, the students provide feedback on the different models, comparing the models to one another and contrasting the models with the data in their moon journal. To focus students' comments, the teacher posts guiding questions on the board, encouraging students to attend to model appearance (e.g., components' location and size), and how each model compares to their data.

Students point out potential limitations in some of the models. For example, students notice that one group used Styrofoam balls of the same size to represent Earth and Moon, and suggest that Earth is actually much bigger than the Moon. There is a brief discussion about whether the size of the orbs is problematic for modeling moon phases. After examining the data from that group, the class determines that although using the same size ball is inaccurate if you are depicting the relative sizes of Earth and Moon, it is not problematic for this purpose. Students also comment on one group's attempt to show Earth's shadow as the cause of moon phases, noting that this model does not show phases that correspond to the moon journal.

Two groups have the correct sequence of moon phases, and a third group has a similar model but with the phases in the reverse order. The teacher asks the class to consider how they might determine the correct order of phases. One student suggests investigating which direction the Moon revolves around Earth. Groups spend fifteen minutes using their materials to investigate what happens if the Moon travels clockwise or counter-clockwise around Earth (looking down from above the model). The teacher circulates, prompting student groups to compare their observations to their moon journals. Students are asked to write about what causes moon phases, comparing the simulated moon phases from the different models they investigated with the data in their moon journals. For example, one group writes:

> *The Moon changes phases as it goes around Earth. The Moon moves around Earth clockwise. Our model showed that the Sun always lights up half of the Moon. As the Moon moves around Earth, people on Earth see just part of what is lit up. The parts that were lit up when the Moon was in different positions in our model matched the phases in our moon journal. And, the order of the phases only matched when the Moon was moving clockwise.*

Day 5:
Students consider the initial myth that they read and are told to imagine that they would be addressing a group of people who believe this myth to be the true explanation for moon phases. The teacher asks the student groups to create a short presentation to convince these people that there is a different explanation for moon phases. Students also are to think about the aspects of their models that they would share in order to support their claim that the lit up portion of the Moon as seen from Earth changes based on the position of the Moon in relation to the Sun and Earth. Some groups decide to video record their revised model to use as evidence, and others decide to present their model using a live demonstration. In creating their arguments, students rely on their Earth-Moon-Sun system model combined with their moon journal data to defend their claim and refute alternative claims beyond the myth (e.g., phases are a result of Earth's shadow).

Students also access resources from the library and online to further explore the position of and relationships among Earth, Moon, and Sun. The teacher prompts students compare what they are finding in these resources to what they found in their investigations, and also to cite and consider the credibility of each source as they gather information. For example, one group applies what they read about the tilt of Earth's axis and discusses the importance of this tilt for the accuracy of their model. After groups develop arguments supporting their explanation of why moon phases occur in a predictable pattern, they create a poster to present their case to the class. During the presentations, the presenters' classmates are tasked with acting as the audience and posing appropriate questions about the group's model and explanation.

As the unit continues, students use their models of the Earth-Moon-Sun system as a starting point to explore seasons and eclipses of the Sun and Moon.

6–8 Physical Science

A sixth grade class is beginning a unit about the nature of matter and the effects of temperature on matter. In this unit, students develop a model based on their examination of evidence for matter existing as particles with empty space between them, and explore the relationships among temperature, state (solid, liquid, gas), particle motion, and particle spacing. The overarching learning goals for the unit are: (1) that matter is made of particles that are in motion and have empty space between them, and (2) this particle model of matter accounts for changes in matter when thermal energy is added or removed.[11]

Day 1:

To start the unit, the teacher introduces a fictional tool that allows students to have an extremely close up view of matter: a super-powerful magnifying glass. The students make drawings of what they think they would see if they looked through this magnifying glass at a variety of substances, including air and water. There are a variety of drawings that students use to represent air and water, including evenly spaced dots, dots connected with lines, and overlapping circles. The teacher asks a few students to explain their drawings to the class, and most indicate that they previously learned that air and water are made up of lots of particles that are in motion.

The teacher explains that today they are going to explore the behavior of matter. The teacher distributes empty syringes without needles to small groups of students, and encourages them to examine the syringes to see how they work. Many students comment on the presence of a hissing sound when the plunger is quickly pulled or pushed, and others respond that the sound is caused by air moving through the nozzle. The teacher then asks the students to move the plunger to the middle of the syringe, block the nozzle with their finger, and then move the plunger. Each group makes observations and lists them on a whiteboard. The teacher then leads a short discussion about their observations. Students explain that they were still able to move the plunger some, but it took more effort, particularly as the plunger got farther from its original

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[11] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

> **DCI: PS1.A: Structures and Properties of Matter**
> Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
>
> **PE: MS-PS1-4**
> Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawing and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

position. Others mention that when they stopped pushing or pulling the plunger it returned to its original position. The teacher then encourages students to consider what might be happening at the super-magnified view. Students make varied claims about what happens to the air samples using evidence from their observations and questioning other groups' claims.

Student 1: *I think some of the air must have leaked out of the syringe when the plunger was pushed because there is no place else for the air to go.*

Student 2: *But if it leaked out, you would have heard it or felt it on your finger.*

Student 3: *Also, if the air leaked out, I don't think the plunger would have gone back to its starting position when you stopped pushing on it.*

Student 4: *Our group thinks that it has to do with the air particles, like in our drawings. When we push the plunger the air can't go out, so the particles get pushed closer together in that smaller space.*

Student 1: *So why does it go back to the original position if you stop pushing?*

Student 4: *I think it goes back because the particles spread back out when you give them more room.*

The teacher thanks the students for their thoughtful comments and asks them to keep these ideas in mind as they move on to the next investigation. Students are given two graduated cylinders and asked to measure out 50 ml of water and 50 ml of alcohol. They then combine the two liquids in a third graduated cylinder, recording the final volume on a provided worksheet. Many groups are troubled when they observe the final volume is about 98 ml. Students record possible reasons for their final volumes being less than 100 ml on their worksheets and then share with the rest of the class. For example, one group says that a group member must have spilled some liquid during the transfer, so they repeat the procedure, taking care to obtain accurate measurements, avoid jostling or splashing of the liquids, and ensure that all liquid is transferred to the final graduated cylinder. Again, they observe the final volume result of 98 ml. Another group suggests that some of the alcohol evaporated before the final measurement was made, reasoning that because they can smell the alcohol, it must be evaporating. These students prepare the 50 ml water sample first and pour it into the final graduated cylinder. They then measure 50 ml of alcohol and *immediately* add it to the final graduated cylinder. They observe that the final volume is still 98 ml. The students are not satisfied, and reason that if evaporation is the "culprit" then they should see a further decrease in volume if they allow the 50 ml alcohol sample to sit in its graduated cylinder open to the room air for a much longer time before transferring it to the final graduated cylinder. They predict the volume after 10 minutes will be well under 98 ml. Once again, they find the volume is 98 ml.

The teacher prompts students to consider what could be happening at the super-magnified view that would explain the 98ml volume; however, the students struggle to come up with ideas to explain the unexpected volume. To help them make sense of the results, the teacher brings out a jar of rocks and a jar of sand. She asks the students to imaging that the rocks are water molecules and that the grains of sand are alcohol molecules. She then pours the sand into the jar of rocks and asks them what they see. Students instantly recognize that the sand fills in the spaces between the rocks. The teacher asks students to discuss with their group how the demonstration might explain what is happening in their graduated cylinders. The teacher then calls on one student to share aloud:

> *Our group thinks that air and liquid are both made of particles. But maybe the particles of one kind of liquid aren't the same size as the particles of another kind of liquid. If one type of particle is smaller than the other type, they could fit into spaces between those larger particles, just like the sand and rocks. That's why the volume of the water and alcohol together was less than 100 ml.*

To conclude the lesson, students are asked to write in their journals whether they agree with the claim that that matter is made of particles that have empty space between them, provide evidence for their position, and include their reasoning for why that evidence supports or refutes the claim. The students all agree with the claim, providing evidence from the experiments they conducted and their reasoning. Students are then given the opportunity to revise their originals drawings, and several students making changes to reflect space between the air and water particles.

Day 2:
The teacher arranges students in small groups and tells them that they are going to continue to explore the behavior of particles of matter by designing experiments to look at the effect of temperature on the movement of odor particles. She describes the supplies that students may choose to use, and distributes an experiment write-up template with labeled sections (e.g., question for investigation, supplies needed, procedures and measurements, observations/results, conclusion). With the teacher's assistance, the students generate scientific questions and use the rest of the class period to plan experiments to detect the effects of temperature on odor particle movement.

Days 3–8:
The student groups carry out their investigations. For example, one group places peppermint oil in a sealed container at the front of the classroom with students spread throughout the classroom in positions that the group has designated on a classroom map. They have students raise hands

when they first smell the peppermint. The students conducting the experiment record the times between the opening of the container and the detection of the odor at the designated positions. This procedure is repeated on successive days with the peppermint oil at different temperatures. For each temperature, the students graph elapsed time versus distance from the sample to each "detector." After drawing best-fit lines, they calculate the slope of each line to determine the average speed of the odor at each temperature. Finally, they plot the average speeds versus temperature.

Day 9:
The teacher instructs student groups to use their completed investigation write-ups to prepare a presentation for the rest of the class. She encourages them to include modifications they made during the investigation, address sources of variation, and relate their conclusions to their data. The students use the remainder of class time to plan their presentations.

Day 10:
The student groups take turns presenting their investigations to the rest of the class. Several groups describe sources of variability and issues they encountered with their procedures. For example, one group thought that people have varying sensitivity for detecting odors and that the non-uniform pattern of detection they find is consistent with this idea. Another group noticed that the air conditioner unit came on in the empty classroom during one of their three trials and made a "breeze" in the room. They discounted the trial and repeated it the next day, turning the air conditioner off just before the experiment. Some groups make statements about their findings in terms of particles, relating increased particle motion to higher temperature or addition of thermal energy.

Day 11:
The teacher distributes several inflated balloons and asks students to note their size. She then puts the balloons in a freezer in the adjacent stock room. Periodically throughout the class period, the teacher has groups of students look at the balloons. Students easily recognize that the balloons are smaller. About midway into the period, the teacher moves the balloons from the freezer to a window sill. After a few minutes the teacher directs students' attention to the balloons. Students comment that the balloons are just as big as when they were originally inflated.

The teacher asks, "How do the changes in the balloon relate to your odor investigations?" Some students point out that both involve different temperatures. Others build on this observation by noting that the different temperatures affect how the particles behaved. A few students refer to the motion of particles, stating that the greater the temperature, the greater the speed of the particles. The teacher asks the students to provide evidence for this claim and they refer to the data they collected in their odor experiments. Other students apply this logic, saying that maybe the balloons were smaller in the freezer because the air particles inside them moved slower.

Day 12:
The teacher leads a review about changes of state, emphasizing a change that students are less familiar with, sublimation. Students are given the opportunity to visit a variety of websites in order to research the relationship between temperature and the sublimation of dry ice. As the students review websites, they record information they consider important in their notebooks. After, the teacher asks students to share what they found and several students summarize the information from websites. For example, one student says that dry ice sublimes faster when the temperature is higher and cites a series of experiments in which chunks of dry ice with the same mass are filmed in containers at different temperatures. The student points out that the amount of solid dry ice remaining at a given time decreased with increasing temperature.

The teacher then conducts a demonstration in which she places small chunks of dry ice in a balloon and seals the balloon opening. Students see that the balloon gradually inflates. The teacher then instructs student groups to draw a model to show what happened with the dry ice in the balloon. Students are also instructed to develop a persuasive case to convince someone else that their diagram is the best model to explain what is going on inside the balloon. The teacher encourages students to draw on ideas from the earlier activities: syringe and water/alcohol mixture, odor motion and temperature, temperature and changes of state, and finally the sublimation of dry ice.

Day 13:
Students present their models and their case as to why their model is the best explanation for what was happening in the balloon with dry ice in it. The teacher encourages students to question each other about the model elements and how they are supported by the evidence the students have gathered, and make suggestions for how the relevant elements and relationships could be represented. Each group has the opportunity to defend their argument by responding to the questions that are presented. The students also compare the different models, examining whether they are based on the same evidence. The whole class then works together to develop a consensus model. They decide to use a series of diagrams that show the balloon inflating at different moments in time. The model shows a gradual decrease in closely spaced blue dots (solid) with small arrows among them and a gradual increase in widely spaced green dots (gas) with larger arrows indicating their greater motion.

The teacher also has each student compare the consensus model to their initial representations of matter at the super-magnified level. Students note differences in how they represented samples of matter and describe to a partner how their thinking about matter has changed. Some students explain that they originally thought that samples of matter, even air, had no empty space ("it's the same all the way through") but now think that it cannot be that way because the particles are moving to some extent, and the same particles can occupy more or less space depending on temperature ("like the balloons") and pressure ("like the syringe").

Cross-Vignette Reflection: Grades 6–8

This section highlights the instances where grades 6–8 students engage with the key elements of each practice in the preceding vignettes. Some key elements can be found in a single vignette while others play out in multiple vignettes.

Practice 1: Asking Questions

The science practice of asking questions is illustrated in two of the vignettes in this grade band.

Key Elements of Asking Questions in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Distinguish between scientific and non-scientific question	X		
B. Generate scientific questions that arise from curiosity, prior knowledge, careful observation of phenomena, models, or emerging data	X		X
C. Construct an appropriate type of scientific question for the purpose of developing scientific knowledge (note: questions may include facets of one or more of these types): i. Descriptive—Identify and characterize relevant aspects (features, functions, processes) of a phenomenon or system ii. Relational—Examine the relationships among relevant aspects (features, functions, processes) of a phenomenon or system iii. Causal—Identify whether a relevant aspect (features, functions, processes) of a phenomenon or system affects another and/or the mechanism for that relationship	X		X
D. Refine/revise scientific questions based on observations/data, models, and/or existing scientific knowledge to more clearly focus the question or explore emerging ideas	X		

In the PS vignette, students generate questions and design experiments to test the effect of temperature on the movement of odor particles (Key Elements B and C). Similarly, in the LS vignette, groups of students are assigned organ systems (e.g., digestive, circulatory, muscular) and asked to develop scientific questions that would help them learn more about these systems (Key Elements B and C). As part of this process, the teacher guides students towards scientific questions that can be tested within a classroom setting (Key Element A). After conducting research on their assigned organ system, students refine their scientific questions to include a focus on the emerging idea of the interactions among organ systems (Key Element D).

Practice 2: Developing and Using Models

The science practice of developing and using models is illustrated in two of the vignettes in this grade band.

Key Elements of Developing and Using Models in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop an appropriate model that will best serve the intended purposes i. Nature of models: a. Descriptive—Represent and characterize relevant aspects (features, functions, processes) of a phenomenon or system, including those that are not visible to the human eye b. Relational—Illustrate relationships among two or more relevant aspects (features, functions, processes) of a phenomenon or system c. Causal—Illustrate how a relevant aspect (features, functions, processes) of a phenomenon or system affects another and the mechanism for that relationship ii. Purpose of models: a. To communicate to others for the purposes of informing, use as evidence for a claim in an argument, eliciting feedback, etc. b. To make predictions (testable hypotheses) c. To compare with other models d. To improve the understanding and/or accuracy of cause-effect relationships or causal mechanisms for a phenomenon or system		X	X
B. Identify the relevant components of the phenomenon/system, relationships among them, and/or potential causal mechanisms to include in the model based on existing scientific knowledge, evidence, and the type/function of the model			X
C. Identify and evaluate merits and limitations of a model (e.g., accuracy, plausibility, clarity, ability to provide insight into the description/processes/causal aspects of a phenomenon or system)		X	X
D. Revise a model based on evidence to improve its accuracy, clarity, complexity, generalizability, accessibility to others, and/or predictive power		X	X
E. Compare multiple models to determine merits and limitations of each in relation to relevant factors such as purpose, scientific evidence, intended audience, predictive power, accuracy, and/or generalizability		X	X

In the PS vignette, students engage in the practice of modeling as they generate drawings to represent what samples of air and water would look like through a fictional tool that provides extremely close up views of these materials. They represent the movement of particles and interactions between particles in a variety of different ways (e.g., dots, shading, lines) (Key Elements A and B). Students in the PS vignette also engage in Key Element B as they create diagrams to show what is occurring inside of a balloon that is being inflated by dry ice. They share their diagrams with the class, and the teacher helps them compare and contrast the various diagrams in order to come to a consensus about how to best represent the relevant elements and the relationships among them (Key Elements C and E). Students then create a consensus model that shows how the balloon inflates at different moments in time, and compare the consensus model to their initial drawings of air as viewed through a fictional tool (Key Element D). Students reflect on how their thinking has changed, and use their emerging understandings about particles of matter and their movement to improve the accuracy of their initial drawings (Key Element D).

In the ESS vignette, groups of students develop causal models to explain moon phases (Key Element A). The students compare the multiple models that were developed and provide feedback on each model's strengths and weaknesses (Key Element E). The teacher posts questions to guide this evaluation process, focusing students' thinking on the appearance of each model, its accuracy, and how it compares to their moon journal data (Key Element C). Students then use what they have learned to revise their models so that they accurately demonstrate the sequence of moon phases (Key Element D).

Practice 3: Planning and Carrying out Investigations

The science practice of planning and carrying out investigations is illustrated in two of the vignettes in this grade band.

Key Elements of Planning and Carrying out Investigations in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Identify what evidence is required to answer a scientific question			X
B. Design different types of investigations (e.g., observational, experimental) to provide valid and reliable data that can be used as evidence to answer different types of scientific questions (e.g., descriptive, relational, causal)			X
C. Carefully and systematically implement an investigation (e.g., make observations/measurements, manipulate/control variables, record data) consistent with the design of the investigation		X	X
D. Revise the design of an investigation as necessary based on preliminary findings or problems that arise with the initial design and/or procedures			X

Both vignettes illustrate opportunities for students to carefully and systematically implement investigations (Key Element C). In the ESS vignette, students manipulate a model and make observations in order to investigate the cause and sequence of moon phases. In the PS vignette, students carry out investigations to look at the effect of temperature on the movement of odor particles. They also students carry out an investigation where they combine two different liquids (water and alcohol) in order to determine and explain the final volume.

The PS vignette also illustrates opportunities for students to engage in key elements of this practice. Students identify the evidence needed to account for the final volume when two different liquids are mixed (Key Element A), and revise their experimental procedure to explore whether evaporation may be the cause for an expected volume reading (Key Element D). Students also design investigations to help explain the effect of temperature on the movement of odor particles (Key Element B). When investigating the movement of odor particles, one group suspects that they air conditioning unit may be influencing their results, so they revise and repeat their experiment with the air conditioning unit turned off (Key Element D).

Practice 4: Analyzing and Interpreting Data

The science practice of analyzing and interpreting data is illustrated in two of the vignettes in this grade band.

Key Elements of Analyzing and Interpreting Data in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Construct a data display (tabular, graphical) that facilitates analysis for answering the question being examined		X	X
B. Systematically compare data from multiple trials or measurements for consistency (within and/or across groups of students) to consider potential sources of error in data collection and/or identify anomalous cases			X
C. Analyze the data using grade-appropriate mathematical/statistical techniques to identify patterns, trends, and relationships			X
D. Consider the limitations of data (e.g., missing data, measurement error) and the implications for the analysis and interpreting results			X
E. Interpret (describe the meaning and relevance of) the results of the analyses for the question being examined		X	X

A particularly important aspect of this practice is for students to organize/analyze data in ways that facilitates interpretation (Key Element A and Key Element C). In both the ESS and PS vignettes, students have opportunities to construct data displays that facilitate understanding of the data in order to answer the question being examined. For example, students in the ESS vignette create moon journals that contain the name and sequence of each moon phase. These journals are used when students later explore the cause of moon phases. In the PS vignette, students construct time versus distance graphs for the spread of odor particles at various temperatures. They then find the slopes of the best-fit line for each the graph to determine the average speed of the odor at each temperature. Finally, they plot the average speeds versus temperatures across all of their trials.

An equally particularly important aspect of this practice is for students to interpret the results of analyses for the questions they are examining (Key Element E). This key element plays out in the ESS vignette as students interpret the data they collected from a simulation and their moon journals in order to explain the cause of moon phases. Likewise, students in the PS vignette interpret the graphs they developed to explain the relationship between temperature and particle motion.

The PS vignette also demonstrates additional key elements of analyzing and interpreting data. Students combine two different liquids and compare data from multiple experimental trials for consistency and potential errors (Key Element B). They also consider potential errors when interpreting the results of their investigation (Key Element D).

Practice 5: Using Mathematics and Computational Thinking

The science practice of using mathematics and computational thinking is illustrated in one of the vignettes in this grade band.

Key Elements of Using Mathematics and Computational Thinking in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Use mathematics and computational thinking to develop and then use models in order to explore a phenomenon (e.g., determine a mathematical relationship to represent a phenomenon, develop a computational simulation to explore a phenomenon)			
B. Use mathematics and computational thinking in data collection (e.g., create an algorithmic procedure for data collection, determine criteria for sampling cases and programming a computer to identify all cases that meet the criteria)			
C. Select and use appropriate mathematical/statistical/computational techniques to organize and analyze data (e.g., determining the best measure of central tendency, examining variation in data, developing a fit line, developing rules for organizing data to make patterns evident)			X
D. Use mathematical or computational models to generate evidence to support a claim when constructing explanations or engaging in argument from evidence			

Students in the PS vignette organize and analyze data that they have collected about the effect of temperature on the movement of odor particles. Students select and use an appropriate mathematical technique to make a claim about the speed of the odor at different temperatures, i.e., graphing elapsed time versus distance from the sample for each detector and then constructing a best-fit line to calculate the slope of each graph to determine the average speed of the odor at each temperature (Key Element C).

Practice 6: Constructing Explanations

The science practice of constructing explanations is illustrated in all three of the vignettes in this grade band.

Key Elements of Constructing Explanations in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Develop a line of reasoning using valid, reliable, and sufficient data as evidence, as well as existing scientific knowledge (e.g., ideas, models, theories) to support a claim	X	X	X
B. Revise explanations based on new evidence and existing scientific knowledge (e.g., ideas, models, theories)	X		
C. When appropriate, seek out and use multiple sources of evidence to support a claim accounting for similar or sets of phenomena	X		

The process of developing a line of reasoning using data as evidence to support a claim (Key Element A) is essential to constructing explanations and is included in all three of the vignettes at this grade range. In the LS vignette, students use evidence from their research to construct explanations about the parts of their assigned organ system and how each part contributes to the whole. In the ESS vignette, students explain the cause of moon phases. In the PS vignette, students construct explanations for the movement of air and water particles and the interactions between these particles.

In the LS vignette, students engage with additional key elements of constructing explanations. Based on information obtained from multiple online and text sources, students revise their initial explanations for how their assigned organ system works with the other organ systems and what role it plays in the functioning of the entire body (Key Elements B and C).

Practice 7: Engaging in Argument from Evidence

The science practice of engaging in argument from evidence is illustrated in two of the vignettes in this grade band.

Key Elements of Engaging in Argument from Evidence in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
Developing Arguments			
A. Determine what evidence, including pertinent details about design, implementation, analysis, might persuade an audience about a model/explanation		X	X
B. Provide, verbally or in writing, a reasoned justification to support or critique a model/explanation using valid, reliable, and sufficient evidence		X	X
C. Evaluate and articulate the strengths and weaknesses of competing models/explanations			X
D. Construct a persuasive case (in writing or verbally) for an intended audience for the best model/explanation for a phenomenon		X	X
Critiquing Arguments			
E. Pose and respond to questions that elicit pertinent details about the important aspects of an argument, including pertinent details about the research design, implementation, analysis, evidence, and reasoning		X	X
F. Use scientific reasoning and evidence to critique an argument, communicating this critique verbally and/or in writing			X
G. When providing a critique of an argument, describe, verbally or in writing, what evidence is needed to further determine the validity of a claim			X
H. Compare and critique multiple arguments on the same topic for whether they use similar evidence and/or differ in their interpretation of the evidence			X
I. Respectfully provide and respond to critiques by citing relevant evidence			X

The practice of engaging in argument from evidence is composed of two parts: developing arguments and critiquing arguments. In both the ESS and PS vignettes in this grade band, students have opportunities to develop arguments. In the ESS vignette, students create short presentations to explain the moon phases (Key Element D). The teacher helps them think about aspects of their models that they would share with others in order to support their claim that the shape of the Moon as seen from Earth changes based on the position of the Moon in relation to the Sun and Earth (Key Element A). In creating their arguments, students rely on their Earth-Moon-Sun system model combined with their moon journal data to defend their claim and refute alternative claims (Key Element B).

In the PS vignette, students verbally use data as evidence to support their claims about the behavior of particles in air and liquids (Key Elements A and B). They develop a persuasive case to convince someone else that their diagram is the best model to explain what is going on with air particles inside a balloon (Key Element D). They also react to one another's claims, pointing out instances where the evidence falls short of supporting the claim (Key Element C).

The ESS and PS vignettes also include examples of students critiquing arguments. In both vignettes, students react to one another's arguments and ask questions that challenge the evidence used to support those arguments (Key Element E). For example, one group of students in the PS vignette argues that air must have leaked out of the syringe when the plunger was pushed because there is no place else for the air to go. Another group challenges this argument, noting that if it did leak they would have heard it and would not have seen the plunger return to its original position when they stopped pushing it. In the same way, students in in the ESS vignette pose questions to one another about their interpretations of Earth-Moon-Sun system models and their corresponding arguments for moon phases.

In the PS vignette, students engage with additional key elements of critiquing arguments. For example, after developing models to explain what is going on with air particles inside a balloon, the students question each other about the relationships of model elements to the data they gathered, and make suggestions for how the relevant elements and relationships could be better represented (Key Elements F and G). Each group then has the opportunity to defend their argument by responding to the questions that are raised (Key Element I). The students also compare the different models presented, examining whether they are based on the same evidence (Key Element H).

Practice 8: Obtaining, Evaluating, and Communicating Information

The science practice of obtaining, evaluating, and communicating information is illustrated in all three of the vignettes in this grade band.

Key Elements of Obtaining, Evaluating, and Communicating Information in Grades 6–8 Vignettes

	Life Science	Earth and Space Science	Physical Science
A. Read and gather information from scientific and technical resources such as books, articles, tables, graphs, models, and community members relevant to the science-related question	X	X	X
B. Evaluate the trustworthiness/credibility of one’s own work and/or other sources according to their reliability, validity, consistency, logical coherence, lack of bias, and methodological strengths and weaknesses	X	X	
C. Distinguish observations from inference, and claims from evidence in one’s own work and/or in other resources	X		
D. Compare and critique information obtained within one’s own work and/or across multiple sources	X	X	
E. Summarize patterns, similarities, and differences in the information obtained from scientific sources	X		X
F. Organize information in appropriate formats (e.g., written, multimedia, visual displays) obtained from one’s own investigations and/or other sources in order to communicate it to various audiences		X	
G. Produce scientific and technical text and make oral presentations that integrate qualitative and/or quantitative information and appropriate representations, from one’s own or others’ scientific investigations, in order to clearly communicate the results		X	

In the LS vignette, students gather information about their assigned organ systems (Key Element A) and the teacher helps them evaluate the credibility of each source (Key Element B). After the students have individually collected and critiqued the information they obtained through their research, they summarize their findings as a group, noting both similarities and differences (Key Elements D and E). The teacher helps them distinguish between claims and evidence as they work together to answer their research questions (Key Element C).

In the ESS vignette, students research the positions of and relationships among the Earth, Moon, and Sun (Key Element A). As part of this process, students compare what they are finding in these resources compared to what they found in their investigations (Key Element D) and also consider the credibility of each source (Key Element B). The students then summarize and organize their research findings (Key Element F), use this information to develop explanations of why moon phases occur in a predictable pattern, and present their explanations to the class (Key Element G).

Students in the PS vignette are given the opportunity to visit a variety of websites in order to research the relationship between temperature and the sublimation of dry ice (Key Element A and summarize the information obtained from various sources (Key Element E).

Grades 9–12 Vignettes

The four vignettes in this section demonstrate how students might engage with the key elements of the practices in grades 9–12. In the life science vignette, biology students explore how traits are determined by DNA and mutagenic factors that can affect variation in traits. The Earth and space science vignette illustrates an Earth science class learning about how Earth's internal structure and properties result in plate motion through thermal convection. The physics vignette focuses on an introductory physics class learning about the relationships among wavelength, frequency, and speed of a wave. The chemistry vignette describes a high school class investigates factors that affect the rate of chemical reactions.

9–12 Life Science

A high school biology class is beginning a unit on heredity. Prior to this unit, the class covered mitosis and meiosis, and learned that meiosis in diploid organisms produces haploid gametes (sperm/ovum). In this unit, students will explore how traits are determined by genes, and investigate changes in genes. The purpose of the unit is for students to develop explanations about (1) how traits are inherited, and (2) mutagenic factors that can affect variation in traits.[12]

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[12] The unit is aligned with, but does not necessarily encompass, the following NGSS DCIs and PEs:

> **DCI: LS1.A: Structure and Function**
> All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. (secondary to HS-LS3-1) (Note: This Disciplinary Core Idea is also addressed by HS-LS1-1.)
>
> **DCI: LS3.A: Inheritance of Traits**
> Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.
>
> **DCI: LS3.B: Variation of Traits**
> In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.
>
> **PE: 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. [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]
>
> **PE: 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. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

Day 1:
The teacher begins by introducing Gregor Mendel's study of inheritance with pea plants, distributing a handout that includes the following information and observations based on Mendel's early work:

- Mating can easily be manipulated by the transfer of pollen between flowers.
- For some properties of pea plants, there are only two possible outcomes (e.g., purple or white flowers – no other colors).
- When mating some pea plants, all offspring have the same trait (e.g., purple and white mating produces only purple flower plants).
- Mating these offspring together produces two sets of pea plants: one that has the same trait as the parents (purple flowers) and one that has the other possible trait (white flowers). The ratio of the traits is consistently 3:1 (e.g., three purple flower plants for each white flower plant).

The teacher instructs groups to use "P" to represent the purple factor and "w" to represent the white factor, and devise a scheme that shows how they can be traced through Mendel's crosses to account for his observations. Most groups quickly come to realize that combining the two factors from one parent with the two factors from another parent produces several possible outcomes. All student groups eventually produce diagrams such as:

Mating of PP x ww

Possible parent factors	w	w
P	Offspring are Pw (purple)	Offspring are wP (purple)
P	Offspring are Pw (purple)	Offspring are wP (purple)

Mating of Pw x Pw

Possible parent factors	P	w
P	Offspring are PP (purple)	Offspring are Pw (purple)
w	Offspring are wP (purple)	Offspring are ww (white)

The teacher asks students to think about any patterns they see in these crosses, making notes in their science journals. He then provides the following discussion prompt, "How are traits, such as flower color, determined in pea plants? How do you know?" After several minutes of group discussion, the teacher calls on several students to share their answers. One student explains:

> *The crosses we just did illustrate how each parent contributes one gene for each trait to the offspring and the combination of genes determines the flower color of the pea plant.*

Another student adds:

> *For each characteristic, including flower color, a pea plant has two copies of a gene, one from each parent. In the crosses we just did, we saw that the combination of those genes determined flower color.*

Day 2:
The teacher asks students to test the scheme they devised yesterday by predicting the outcome of a cross between a purple (Pw) plant and a white plant (ww). After few minutes of discussion and testing, a volunteer presents her group's prediction:

Mating of Pw X ww

Possible parent factors	w	w
P	Offspring are Pw (purple)	Offspring are Pw (purple)
w	Offspring are ww (white)	Offspring are ww (white)

The teacher then asks how many of 100 total offspring of this mating would have purple flowers and how many would have white flowers. All students agree that the scheme predicts 50 of each. The teacher informs students that a 1:1 ratio is consistent with what Mendel observed. The teacher also emphasizes that Mendel saw the same patterns of inheritance for other pea characteristics. Using the scheme they developed and the method of problem solving they used for this introductory example, students work through genetics crosses of several additional characteristics of pea plants, such as plant height and seed shape.

The teacher invites students to explain what they concluded about inheritance from analyzing Mendel's observations. From the discussion, the class agrees on the following:

- Both parents contributed equally to the traits of the offspring.
- There was no mixing or blending of traits.

- Because all Pw plants have purple flowers, one factor can be dominant over another.

The teacher helps students extend their conclusions by applying scientific terminology. Students learn that the factors from Mendel's observations are called alleles and each of the pea plant characteristics they examined is controlled by a single gene that has two possible alleles. The teacher provides opportunities for the students to practice using this language as they take turns explaining their conclusions to a partner.

Day 3:
The teacher notes the class has thus far discussed scenarios in which particular traits were stable. For example, if pea plants had a P allele, their flowers were purple—the allele, and thus the flower color, did not become modified over generations. The teacher then asks students to describe situations they might know about where genetic material changes over time. Students offer a variety of suggestions. For example, one student mentions a news story that described the problems associated with antibiotic resistant bacteria. The teacher asks what may have caused these changes, and students suggest such things as chemicals, nuclear waste, and ultraviolet light. The teacher confirms that DNA can be changed over time by the factors the students suggested, calling this process "mutation."

Next, the teacher introduces an activity in which students will test various agents for their ability to change DNA and modify an organism's traits. The teacher tells the students that, in contrast to the multi-cellular pea plants they have been talking about, they will now conduct their experiments using a single-celled bacterium. The teacher explains that this bacterium reproduces asexually by mitosis, forming colonies of identical cells; consequently, any different in a treated colony to the control colony would indicate a mutation. The teacher then demonstrates basic bacterial culturing methods, and the students practice these methods for the remainder of the lesson.

Day 4:
The teacher instructs groups to think about agents that can cause genetic changes and to formulate a specific, testable question about factors that cause mutations. As they work, the teacher circulates to help them refine their questions, reminding them that questions that depend on such things as personal preference, moral values, or non-measurable phenomena are not suitable for a scientific investigation. The groups produce a variety of questions encompassing many different agents and exposure schemes. For example, one group wonders whether ultraviolet (UV) light affects bacteria, and plans to vary the time of exposure at a set distance. Another group wonders if salt will cause mutations, and plans to test various salt concentrations.

Once the teacher checks the safety and feasibility of their plans, the groups design detailed procedures. The various groups suggest different methods for assessing growth. For example, some will use the number of colonies formed while others will examine the sizes of colonies formed. Some groups decide to make duplicate or triplicate samples for each condition to have "back-ups" or to calculate averages. The groups then make predictions about what they expect to happen and systematically carry out their procedures. Each group records their data in a chart, noting differences among the various trials.

Day 5:
Students continue their investigation, analyzing their data to examine colony growth in their experiments. Some groups see the growth patterns they had predicted, while other groups do not. In cases where the results are not as expected, the teacher helps students think about modifications to their experiments that could address any potential errors. The teacher also helps students think about how errors in their data might impact the analysis and interpretation of their results. For example, one group interprets a lack of effect as indicating that their UV light exposure was not sufficiently long and repeats their experiment with longer exposure times. Another group suspects that contamination occurred, so they repeat their experiment to address this potential problem.

Day 6:
After reviewing the data from the students' revised experiments, the teacher asks one group to summarize their experimental design, data, and results on the smartboard. In the discussion that follows, other students in the class ask questions about the investigation and suggest possible modifications to strengthen the experimental design. The teacher then has each student construct an explanation based on the results of this group's experiments. For example:

> *These data show that UV light does not cause mutations to bacteria with brief exposure. When subjected to only three minutes of UV light, there were no differences seen in colony growth. However, when subjected to one hour of UV light, mutations did occur. The bacterial colony in this case was much smaller than the control.*

Because there is some variation in the students' explanations, the teacher divides them into groups to discuss the strengths and weaknesses of these competing explanations and the extent to which they differ in their interpretation of the evidence presented.

Day 7:
The teacher prompts students to think about what they learned yesterday about what makes a good explanation. She then provides time for each group to develop an explanation for their own experiment and share it with others on their class' website. When they are done, the teacher instructs each group to produce written critiques of the other groups' explanations. For example, one group writes:

In order to provide more evidence for the explanation that long exposure to UV light causes mutations, more experiments with different types of single-celled bacterium are needed.

To conclude the lesson, each group spends time responding to their peers' critiques in writing.

9–12 Earth and Space Science

A high school class is beginning a unit about tectonic-plate motion. Students have already studied the nature of plates and events that occur at plate boundaries. The overarching learning goal for the unit is for students to build a model that represents their understanding of how Earth's internal structure and properties result in plate motion through thermal convection.[13]

Day 1:

Students are asked to discuss in small groups what they have learned so far about plates through previous online information searches, class activities, and discussions. Much of the discussion focuses on Earth's surface consisting of abutting plates, and that interactions at plate boundaries cause characteristic features (e.g., mountain formation, earthquakes, and volcanoes). The students are then asked to provide evidence for plate movement and describe:

- the patterns of magnetic field reversals in rocks of the mid-Atlantic crust;
- that similar fossils are found in rocks of the same age on the shores of continents that appear as if they would fit together like pieces of a jigsaw puzzle; and
- the characteristic sediments from different continents align in models that "rejoin" continents as Pangea.

The teacher says that they will be exploring the question, "How does Earth's structure cause plate motion?" and asks students what kinds of things they would need to know to understand what makes the plates move. Some students refer to forces being involved in motion and others

[13] The unit is aligned with, but does not necessarily encompass, the following NGSS DCIs and PE:

DCI: ESS2.A: Earth Materials and Systems
Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.

DCI: ESS2.B: Plate Tectonics and Large-Scale System Interactions
The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

PE: HS-ESS2-3
Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

suggest that they need to know where the energy for plate movement comes from. Students are then asked to draw on their prior knowledge to individually generate a diagram showing the structure of Earth from the surface to the center. They are instructed to label layers and their composition, and to indicate their initial thinking about what causes Earth's plates to move.

Day 2:
The teacher introduces a guest geologist from the local university who gives the class a historical perspective about differing ideas for what drives the motion of Earth's plates. First, the geologist outlines the "expanding Earth" idea that was proposed in the late 19^{th} century, which centers on the gradual growth in the size of Earth because of expansion caused by internal heat. According to this idea, all land masses were initially one continent. The expanding surface produced volcanoes that caused cracks in the continent that in turn broke the continent into different pieces. The smaller land masses then drifted apart as expansion zones between them continued to widen.

The geologist then describes a second idea, which also relies on Earth's internal heat as a source of motion at the surface. This idea, proposed in the early 20^{th} century, focuses on the internal heat forming convection currents (or convection cells) within Earth that result in lateral movement of materials in the upper mantle. The lateral movement of this mantle material in turn causes Earth's plates to move relative to each other, sometimes separating and sometimes colliding at their boundaries. The geologist also explains that more recently, GPS data indicate that some surface locations on Earth are moving apart from each other and others are moving closer together.

Periodically during the presentation, students are asked to relate the new evidence and ideas to what they already understand about Earth's structure. For example, several students point out that the ideas presented by the geologist were consistent with some of the phenomena (e.g., volcanoes) that they had already learned about. Students are also asked to consider how the information being presented relates to the question of what drives plate motion.

Day 3:
Students share their diagrams showing the structure of Earth in small groups, and consider how they might revise them in light of the geologist's presentation. The teacher emphasizes that the question, "How does Earth's structure cause plate motion?" should be addressed in their diagrams. The teacher circulates while groups discuss the strengths and limitations of their initial models, and use information from the geologist's presentation to inform modifications to their individual diagrams. Ultimately, each group collaboratively develops a consensus diagram. Students also consider the reliability of sources of information as they plan revisions. For example:

Student 1:	*All of the information was equally reliable because a professional geologist presented it.*
Student 2:	*I disagree. I think that findings from the more recent data are most reliable because experimental methods have improved.*
Student 3:	*Yes, but the geologists referenced specific articles in professional journals. I think that means the information was all reliable.*

Day 4:
The teacher reminds students of a demonstration that many students observed in middle school: when hot water, room temperature water, and cold water are combined in one beaker, the hot water sits above room temperature water, while the cold water sinks below the room temperature water. The group discusses how this demonstration shows the effect of temperature on the density of a substance, and thus on the relative position of samples of the substance at different temperatures.

The teacher then introduces an activity for students to investigate what happens when a material is heated unevenly. Each small group of students is given a glass baking dish nearly filled with vegetable oil with flakes of thyme suspended in the oil. The teacher explains that thyme soaked in vegetable oil has a density very close to that of the vegetable oil itself and thus does not sink or rise to the surface. Students quickly observe that they can use the movement of the thyme, which they can easily see, as an indicator of the movement of the vegetable oil itself. The teacher asks the students to discuss in their groups what they can observe and what they can infer thus far. Students conclude that they are able to observe the movement of thyme leaves, which lets them infer the movement of the vegetable oil. For example:

> *We can see the thyme leaves move. That is an observation. We know the thyme is floating in the oil, so the oil must be moving if the thyme is moving. That is an inference. We can't see the oil move, but we are pretty sure that is what is happening.*

Students are given an electric heating unit and supports to hold the baking dishes above the heat source. Each group plans an investigation that will provide evidence required to answer the question, "What is the effect of heat on the oil samples?" Different groups decide to place the heat source at different locations under the baking dishes (e.g., centered under the dish, offset to one side, at a corner).

Day 5:
Students conduct the experiments they planned the previous day. After a few minutes, students observe that the thyme flakes begin to move slowly. With the teacher's prompting, the students decide to describe the motion by noting the direction of "thyme travel" and by measuring either the time required for a time flake to travel a given distance, or the distance it travels given a set

amount of time. The groups then represent the motion they observe in labeled drawings. For example, one group generates a pair of drawings, an overhead view and a side view, to provide a more complete display of their observations which identifies the relationships among the components of the set up.

As students discuss their observations within groups, they recognize that the heating causes somewhat circular motion of the thyme flakes. Those who placed the hot plate under the center of the baking dish also recognize that two of these flows are established, one on each side of the dish.

Day 6:
Students repeat the vegetable oil activity, introducing a small slabs of wood that rest on the surface of the oil to represent Earth's plates. The students observe that the slabs move laterally in the same direction that the thyme flakes move just beneath them.

Students then revise their group diagrams based on what they have learned from the investigation about what causes the plates to move. Some groups add horizontal arrows to show plates moving away from an area with relatively hot material rising through the mantle. Others use arrows to represent sets of paired circular flows on either side of rising hot material. Additionally, some groups now label the upper mantle as a liquid.

Day 7:
Student groups use a poster session format to present their diagrams to others in the class, in which they describe their diagrams and rationale for what they included. Students also take notes about strengths and limitations they perceive in other groups' models, and pose questions to their classmates about their arguments and their experimental design. Each group is given the opportunity to respond to their classmates' questions, citing evidence from their investigations and providing clarification about their experimental design to support their argument. For example, when viewing diagrams that show that Earth's plates float on the liquid mantle, some students engage in extended discussions about the state of the upper mantle and how similar Earth's structure is to the wood-on-oil representation. Several students say that they can use the general idea of heat causing material to move in a pattern, but that it must be different for the mantle because it cannot flow as easily as vegetable oil.

Day 8:
The teacher leads an extended discussion aimed at building a consensus diagram that reflects what the class has learned from its investigations. He encourages students to make suggestions based on the strengths and limitations they noticed in the different groups' diagrams. He also repeatedly prompts students to articulate their thinking, asking students why particular elements should be included or omitted, and why particular relationships should or should not be

highlighted. For example, in this discussion, one student suggests modifying the diagram using gradations of shading to indicate differential density of materials in the upper mantle. In addition, there is broad agreement among students in the class that the model should clearly show heat from radioactive decay deep within Earth creating convection currents as it dissipates unevenly toward Earth's surface. The class also supports a student's suggestion to include arrows to represent some convection currents that lead to collision at plate boundaries and others that lead to plates spreading apart.

9–12 Physics

A high school introductory physics class has recently started a unit on waves. The unit started with an initial discussion that allowed students to share what they already knew about waves (e.g., water waves at the ocean, cheers in a football stadium). Then, the class was given some long (2 meter) springs and asked to identify two different ways of making waves. In doing so, they created both transverse (sinusoidal) and longitudinal (compression) waves. Through some brief experimentation, students discovered that they can manipulate both the amplitude and frequency of the waves. In the rest of the unit, students will investigate, model, and develop explanations for a variety of wave phenomena. The learning goal for the sequence of lessons that follows is for students to understand how the wavelength, frequency, and speed of a wave are related.[14]

Day 1:
The teacher asks students to discuss in their lab groups what they are interested in learning about waves, and to phrase their interests as questions. After the students talk in their groups, they have a class discussion about their interests, and the teacher records their questions on the white board in three columns. Their questions include:

> Column 1:
> *What happens when two waves collide?*
> *What does the "wavelength" really mean?*

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[14] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

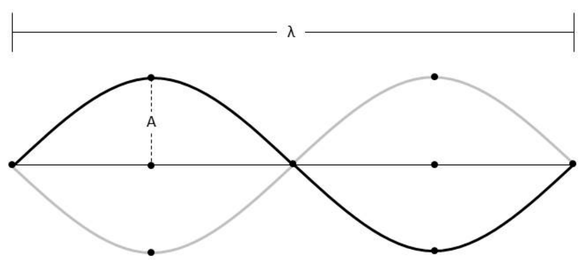
> **DCI: PS4.A: Wave Properties**
> The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.
>
> **PE: HS-PS4-1**
> Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]

Column 2:
We've seen waves in water, in the spring; can waves travel through anything? How does what their traveling through matter?
What is the relationship between how big a wave is and how fast it moves?

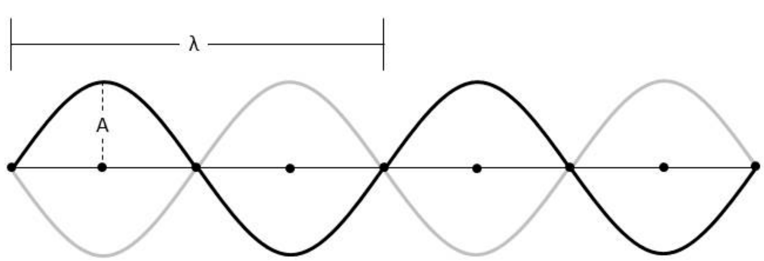
Column 3:
Why do waves bounce back sometimes and not other times?
Why are some waves in the spring big and others small?

The teacher tells the class that they will have the opportunity to investigate many of these questions in this unit. She then asks the class, "Why do you think I put the questions in three columns? What is similar about the questions in a column and what is different among the columns?" The students have several ideas, but most agree that the questions in the first column are about describing waves or wave phenomena, the questions in the second column are about relationships, and those in the third column are about what causes waves to act in certain ways.

Next, students are shown a "standing wave" apparatus that has a string tied to a fixed post on one end and to a small motor on the other end. The teacher turns on the motor and the string forms the following pattern:



The students discuss their observations, noting that the wave is flipping upside down really quickly, but looks like it is not changing. They also notice that some parts of the string do not appear to be moving. The teacher then turns one of the control knobs on the motor, which causes the height of the wave to change, then turns another knob which causes the wave pattern to change to the following:



The students discuss how the waves are different, and with the teachers' guidance, the class agrees to call the height of the wave the "amplitude" (A) and the distance for a full wave cycle the "wavelength" (λ). They also comment that changing the amplitude seems to have no effect on the wavelength, and vice versa.

To wrap up the lesson, the teacher lets the class know that tomorrow they will begin a series of investigations to help answer one of the questions they came up with:

> *We've seen waves in water and in the spring. Can waves travel through anything? How does what they're traveling through matter?*

Their homework assignment is to brainstorm how they might go about answering this question, including what data they would need to collect.

Day 2:
The lesson begins with students sharing their ideas from the homework assignment. Although some students have suggestions for investigations, several point out that the question is very broad. For example, one student says, "How does what their traveling through matter? Matter in what way? Are we talking about the wave's amplitude? Its wavelength? How fast it goes?" A second student says, "We know that light can't travel through solid materials, so waves can't travel through anything." Another student responds, "I wasn't thinking about light waves, but waves more like water and sound."

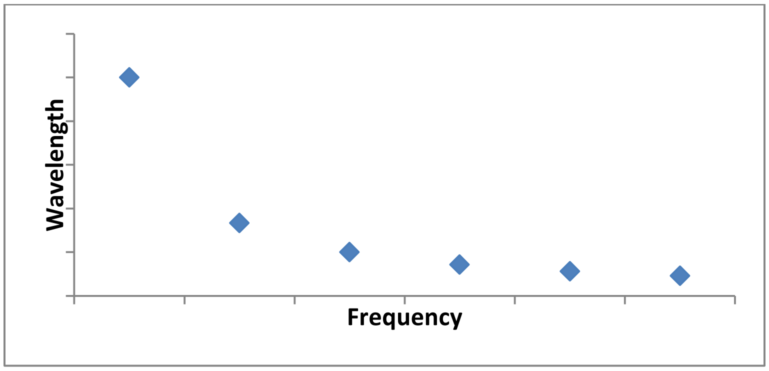
The class agrees that the question needs to be better specified, so the teacher has them get into their lab groups to work on refining the question, suggesting that they may end up with several, very specific questions from this one broad question. During this time, the teacher moves from group to group, asking questions that help them refine their research questions. Their refined questions include:

> *How does the speed of a wave depend on what it is traveling through? Are there differences depending on the type of wave (e.g., light, sound, water)?*
>
> *What is the relationship between wavelength, frequency, and wave speed? Does this relationship depend on what type of wave it is or what it is traveling through?*

Next, the teacher asks the lab groups to (1) determine what data they would need to collect to answer these questions, and (2) design an investigation to collect those data. To help structure this task for them, she suggests that they first think about investigating these questions for the waves in the springs, using the variety of long springs that she has (the springs vary in the tightness of the coils). The students work in their groups developing responses to these two tasks, and then each group presents their plan to the whole class. During each group's presentation, the rest of the class asks questions, and by the end of the class have agreed on an investigation that all groups will try. The consensus is that, because they can control the frequency at which waves are generated, they should measure wavelength and speed for several different frequencies. Because the action will happen pretty quickly, they also plan to capture the wave motion on their cell phones and do a video analysis of the motion. They also agreed that they should do this experiment with different springs to see how that affects the results.

Days 3–4:
The students set to work implementing their planned investigation, with each group using a different spring. Each group records multiple videos, one each for a variety of frequencies. After data collection, the students use a computer program for the video analysis that allows them to measure the wavelength and how much time it takes for a wave to travel the length of the spring (from which they can calculate the speed of the wave). They develop a data table to record this information, with columns for frequency, wavelength, time, and speed. Two findings jump out to each group. First, the calculated speed is very similar across trials, regardless of the wave frequency. Second, as the frequency increases, the wavelength gets smaller.

To help them make sense of their data, the teacher suggests they graph their data to examine whether there is a mathematical relationship. Because wave speed is essentially constant for each group, they decide to try graphing frequency versus wavelength, which results in a graph like the following:



The students recognize the shape as an inverse relationship. Because they learned a graphical analysis technique for determining the relationship among variables that requires a linear relationship, they decide to calculate the inverse of the frequency and graph that versus wavelength. The new graph results in a fairly straight line, though some of the points fall above and some below the line. They then determine the equation of that line starting with y = m*x + b, substituting in the quantities they measured, giving them: wavelength = m * 1/frequency + 0. They also see that the slope of this second graph is very similar to the wave speed they calculated using distance and time, and after conferring with the other groups (who found a similar relationship), decide they can write the equation as:

wavelength = wave speed/frequency

The groups make whiteboard presentations of their results, supporting their conclusions with data from the investigation. During each presentation, the teacher and other students ask questions about the findings. For example, the teacher asks a group why they think their data did not fall perfectly on the straight line, and the class engages in a discussion of sources of error in the experiment, with the largest likely source of error being identifying the exact same part of the wave during the video analysis, which could have thrown off their measurements.

The class notices that each group had a constant wave speed, though each groups' wave speed was different from the others'. They decide to make a table listing the wave speed and spring used, ordering the data from highest speed to lowest speed. They then put the springs in this order and see that the fastest wave was in the spring with the tightest coils and the slowest wave in the spring with the loosest coils.

Days 5–19:
Over the next several lessons, the class investigates how various factors affect the speed of various types of waves. One set of experiments focuses on surface waves in a tank, varying both the depth of the liquid and its composition (e.g., using water, salt water, a glycerin-water solution). They also use data from the Internet to examine the behavior of light and sound waves as they travel through various substances. They then go on to investigate a number of the other questions they initially raised about waves.

Days 20–23:
As the class is wrapping up its investigations of wave phenomena, the teacher tasks each group with developing a virtual presentation for one of the questions the class investigated. Students are asked to include the following elements in their presentation and post it on the class Edmodo website:

1. Question investigated
2. Procedures
3. Data summary/representation
4. Conclusion, including
    a. their answer to the question;

b. how the data support that answer; and
c. strengths and limitations of the procedures used to collect and analyze the data.

The class is given two days to develop their presentations and post their work. Student then work in their groups to review other group presentations and post questions they have, making note of whether the arguments for each research question use similar evidence or differ in their interpretation of the evidence. Prior to doing so, the teacher provides students with guidelines for the types of questions they should be asking of other groups (e.g., respectful, elicit clarification on experimental procedures or data analysis methods, alternative explanations considered and how the results may or may not refute those explanations). After all groups have reviewed each presentation and posted questions, the groups respond to the questions about their presentation, providing pertinent details related to their design, analysis, evidence cited to support their claims, etc.

Groups then review the presentations a second time and, when appropriate, critique various aspects of the research, again posting these critiques on the Edmodo site. The teacher reminds the class that they need to cite evidence from the presentation to support their critique and continue to be respectful. Afterward, each group presents their online work to the entire class and responds to any critiques noted by other groups.

9–12 Chemistry

During a unit on chemical reactions in a high school chemistry class, students have explored simple synthesis reactions. They have developed a general explanation for such reactions based on the particle model of matter, describing how atoms and molecules interact with each other (typically through collisions) and recombine in different arrangements. They have also discussed evidence of chemical reactions—for example, change in color and production of a gas. The teacher now wants students to consider what factors, if any, might affect how fast a reaction occurs (or the rate of reaction). The overarching learning goal for this part of the unit is for students to understand how and why certain factors affect chemical reaction rates within the context of the particle model of matter. Students will design and implement investigations, ultimately constructing an explanation for their findings.[15]

[15] The unit is aligned with, but does not necessarily encompass, the following NGSS DCI and PE:

DCI: PS1.B: Chemical Reactions
Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

PE: HS-PS1-5
Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants;

Day 1:
The teacher gives each lab group a beaker of room temperature water and an effervescent antacid tablet. She asks students to drop the tablet in the water and observe, then discuss in their groups what evidence indicates that a chemical reaction may be occurring. After giving the groups time to talk, the teacher brings the class together to discuss. A class consensus forms that although the tablet dissolving is not necessarily evidence of reaction, the bubbles that appear indicate a gas is being produced, suggesting a reaction did occur.

The teacher then asks students to consider whether it might be possible to make the reaction go faster or slower, and what data students could collect that would indicate that the rate of the reaction is changing. Students discuss these questions in their lab groups and then summarize their thoughts on the group's whiteboard. One member from each group then presents the ideas to the rest of the class. With regard to the rate of reaction, the two most common proposals are changing the temperature of the water and breaking the tablet up into smaller parts. However, when questioned by the teacher, students struggle to articulate a rationale, saying instead that in their experience things just dissolve faster when water is warmer and when the bits of solid are smaller. With regard to data that they could collect to measure the rate of reaction, the class identifies two possibilities: (1) the amount of time it takes for all of the solid to disappear, and (2) the amount of time it takes for fizzing to stop.

The teacher asks students to turn their ideas into questions they can investigate. Students begin suggesting possibilities, and in a whole class discussion, the following questions are agreed upon:

1. How does temperature affect reaction rate?
2. How does the size of a solid particle affect reaction rate?

The teacher tells the class that tomorrow they will design investigations to address these questions, but in the meantime they should keep thinking about an explanation for why the proposed factors might affect reaction rate. The teacher reminds students that an explanation should include a claim and evidence, as well as reasoning about how the evidence supports the claim.

Day 2:
The teacher calls on several students to summarize the ideas generated the previous day. She records the responses on the board at the front of the room:

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evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

- Factors that might affect reaction rate: (1) water temperature, (2) size of the tablet pieces.
- Possible data about reaction rate: (1) time it takes for all solid to disappear, (2) time it takes for all fizzing to stop.

The teacher then instructs students to design an investigation that tests only one factor (temperature or size of tablet pieces) using only one type of data about reaction rates (time it takes for solid to disappear or for the fizzing to stop). In lab groups, students plan their investigations, listing the materials and steps on their whiteboard. The teacher circulates and asks clarifying questions but does not critique the plans.

When all groups are done, the teacher commends students on developing a preliminary plan for the investigation. She tells them that before they actually conduct the investigation, she wants them to try out their procedures (e.g., measuring water temperature, breaking the tablet in pieces, observing how long the solid takes to disappear). She gives them 15 minutes before the class period ends, instructing them to make notes about any revisions needed. She points to the materials she collected and tells each group to designate one member to come forward and gather what the group needs. For the next 15 minutes, students test their procedures. Before the period ends, the teacher asks each group to share any problems they encountered and asks the rest of the class to comment on potential solutions. Reports from the groups include:

- One group said they were not sure how to standardize the temperature of their water, and they thought this would be important for comparing their results with those of other groups. One student suggested that the teacher prepare standard water samples for students to use—a sample of ice water (~0° C), a sample at room temperature (~21° C), and a sample heated to about twice room temperature (~42° C).

- One group that ground up the tablet was surprised that some of the solid stuck to the mortar and pestle, which they thought would influence the results. The group realized that they needed some tool for scraping as much of the solid off as possible. Another group suggested they use a scoopula, like they had used in an earlier investigation.

- Three groups noticed that sometimes the tablet or pieces floated to the top of the water, which made it hard to tell when all of the solid had disappeared. Other groups said it was easy to tell when the fizzing stopped. On this basis, all groups decided to observe fizzing rather than disappearance of the solid.

The teacher concluded by stressing the importance of testing experimental procedures and told students that tomorrow they would revise their investigation plans and carry them out.

Day 3:
For today's class, the teacher divides the students in two groups, all who planned to investigate the size of the tablet piece and all who planned to investigate water temperature. She tells each large group to generate one standard investigation plan that individual lab groups will implement so they can compare results. She also tells the groups to specify how they will record their data. The two groups come up with the following templates:

Water Temperature

1. Record the temperature on the thermometer in the class supply of ice water.
2. Pour 500 mL of ice water from the class supply into a 1000 mL beaker, but do not let any ice pour into the beaker.
3. Drop an intact effervescent antacid tablet in the beaker and start the timer (a student's phone) when the tablet hits the water.
4. Stop the timer when fizzing stops and record the time elapsed.
5. Rinse the beaker with room temperature water from the class supply.
6. Repeat steps 1–5 twice.
7. Do steps 1–6 for room temperature water and then for heated water.

Trial	Water Temp. (° C)	Fizz Time (sec)
1		
2		
3		
4		
5		
6		
7		
8		
9		

Size of Table Piece

1. Record the temperature on the thermometer in the class supply of room temperature water.
2. Pour 500 mL of room temperature water from the class supply into a 1000 mL beaker.
3. Drop an intact effervescent antacid tablet in the beaker and start a stopwatch as soon as the fizzing starts.
4. Stop the timer when fizzing stops and record the time elapsed.
5. Rinse the beaker with room temperature water from the class supply.
6. Repeat steps 1–5 twice.
7. Do steps 1–6 again, first for a tablet broken in four pieces (as equal in size as possible), and second for a ground-up tablet.

Trial	Water Temp. (° C)	Size of Table Piece	Time elapsed (sec)
1		Whole tablet	
2		Whole tablet	
3		Whole tablet	
4		~1/4 of a tablet	
5		~1/4 of a tablet	
6		~1/4 of a tablet	
7		Ground up	
8		Ground up	
9		Ground up	

For the rest of the class period, lab groups carry out their respective investigations. The teacher tells them that tomorrow they will share their results and formulate an answer to their investigation question. She also asks them to keep thinking about how to explain their findings.

Day 4:

As the class begins, the teacher reminds students that their goal is to explain their findings, but first they are going to present their findings to the rest of the class and answer their investigation question. Each group has recorded their data table on a whiteboard, which the group brings to the front of the class to present their findings. The water temperature groups go first, reporting strikingly similar findings. Each group found that as the temperature increased the fizz time decreased. The teacher asks one group to state their findings in the form of an answer to their research question, “How does temperature affect reaction rate?” One member of the group replies, “Our data show that as water temperature increases, fizzing stops quicker, which means the reaction is going faster, or the rate is increasing.” The groups that tested size of tablet piece also had very similar data, finding that the smaller the piece, the faster the reaction rate.

The teacher congratulates the students on their thorough investigation plans and the care with which they were implemented. She asks them to think back to when she asked them to explain why the factors they identified would affect reaction rate. She reminds them that at the time, their answers were based solely on what they had experienced in the past, not on scientific reasoning. She asks them if they have had any other thoughts since that first day. One student says that she thinks it has something to do with what they learned earlier in the year about temperature, specifically that temperature is a measure of the motion of the particles. Another student picks up on the thought, saying that molecules of warmer water must move faster than molecules of colder water.

Another student says he has been thinking about how the unit on chemical reactions began, with the students considering the particle model of matter and how chemical reactions are about small particles (or molecules) colliding. He wonders if this is part of the explanation for why water temperature and size of tablet piece affect reaction rate.

The teacher stops the discussion and asks students to reconvene in their lab groups to try to explain their findings, keeping in mind the ideas students have just brought up. After about 15 minutes, the teacher asks two lab groups (one for each factor) to present their explanations:

> *Increased temperature increases the reaction rate because more collisions between molecules are happening. When we dropped the tablet in warmer water, the fizzing stopped sooner than in the cold water, and that tells us the reaction rate was greater. We know that water molecules are moving around faster in warmer water, and if they're moving around faster, they should collide with other kinds of molecules more than if the water molecules are moving slower. And if there are more collisions, the reaction goes faster.*
>
> *When the tablet pieces are smaller, the reaction rate is higher because there are more collisions between the water molecules and the tablet molecules. When we compared the fizz time for the whole tablet to the fizz time for the chunks and ground up pieces, we saw that the smaller the piece, the smaller the fizz time. We realized that by making smaller pieces, we were exposing more of the tablet molecules to the water, and that meant there could be more collisions between the tablet molecules and the water molecules. More collisions equals higher reaction rate.*

As the class is ending, the teacher asks the students whether their investigations and explanations have made them wonder about other factors that might affect reaction rate. One student responds, "So, if reaction rate is all about how many collisions happen, I wonder if there's a way to get more molecules involved. If there were more molecules, it seems like there would be more collisions, and that should increase the reaction rate." The teacher thanks the student for her contribution and says that as it turns out, the class will be exploring that possibility over the next couple of lessons.

Cross-Vignette Reflection: Grades 9–12

This section highlights the instances where grades 9–12 students engage with the key elements of each practice in the preceding vignettes. Some key elements can be found in a single vignette while others play out in multiple vignettes.

Practice 1: Asking Questions

The science practice of asking questions is illustrated in two of the vignettes in this grade band.

Key Elements of Asking Questions in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Distinguish between scientific and non-scientific question	X			
B. Generate scientific questions that arise from curiosity, prior knowledge, careful observation of phenomena, models, or emerging data	X		X	
C. Construct an appropriate type of scientific question for the purpose of developing scientific knowledge (note: questions may include facets of one or more of these types): i. Descriptive—Identify and characterize relevant aspects (features, functions, processes) of a phenomenon or system ii. Relational—Examine the relationships among relevant aspects (features, functions, processes) of a phenomenon or system iii. Causal—Identify whether a relevant aspect (features, functions, processes) of a phenomenon or system affects another and/or the mechanism for that relationship	X		X	X
D. Refine/revise scientific questions based on observations/data, models, and/or existing scientific knowledge to more clearly focus the question or explore emerging ideas			X	

Students in the LS, chemistry (CHEM), and physics (PHY) vignettes construct scientific questions for specific purposes (Key Element C). In the LS vignette, students generate scientific questions about factors that may cause mutations, such as ultraviolet light and salt. Students in the CHEM vignette construct questions about factors that may affect the rate of a chemical reaction, including temperature and the size of a solid particle. Students in the PHY vignette develop and then categorize their questions about waves into three categories: (1) those that describe waves, (2) those that are about relationships, and (3) those that are about what causes waves to act in certain ways.

The student questions in the LS vignette are based on student curiosity and prior knowledge of factors that cause mutations (Key Element B). As students generate their questions, the teacher helps them distinguish between scientific and nonscientific questions, reminding them that scientific questions must be testable/measurable (Key Element A).

Student in the PHY vignette draw upon their interest in waves when developing questions (Key Element B). However, after observing a standing wave apparatus and discussing their observations, students determine that their questions are too broad. Students then work in groups to revise the questions so that they are clearer and more specific (Key Element D).

Practice 2: Developing and Using Models

The science practice of developing and using models is illustrated in one of the vignettes in this grade band.

Key Elements of Developing and Using Models in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Develop an appropriate model that will best serve the intended purposes i. Nature of models: a. Descriptive—Represent and characterize relevant aspects (features, functions, processes) of a phenomenon or system, including those that are not visible to the human eye b. Relational—Illustrate relationships among two or more relevant aspects (features, functions, processes) of a phenomenon or system c. Causal—Illustrate how a relevant aspect (features, functions, processes) of a phenomenon or system affects another and the mechanism for that relationship ii. Purpose of models: a. To communicate to others for the purposes of informing, use as evidence for a claim in an argument, eliciting feedback, etc. b. To make predictions (testable hypotheses) c. To compare with other models d. To improve the understanding and/or accuracy of cause-effect relationships or causal mechanisms for a phenomenon or system		X		
B. Identify the relevant components of the phenomenon/system, relationships among them, and/or potential causal mechanisms to include in the model based on existing scientific knowledge, evidence, and the type/function of the model		X		
C. Identify and evaluate merits and limitations of a model (e.g., accuracy, plausibility, clarity, ability to provide insight into the description/processes/causal aspects of a phenomenon or system)		X		
D. Revise a model based on evidence to improve its accuracy, clarity, complexity, generalizability, accessibility to others, and/or predictive power		X		
E. Compare multiple models to determine merits and limitations of each in relation to relevant factors such as purpose, scientific evidence, intended audience, predictive power, accuracy, and/or generalizability		X		

Students in the ESS vignette use their prior knowledge to individually generate a diagram showing the structure of Earth from the surface to the center. Students label layers and their composition, and indicate their initial thinking about what causes Earth's plates to move (Key Elements A and B). Following a class visit from a local geologist, students discuss the strengths and limitations of their initial models and use information from the geologist's presentation to inform modifications to their diagrams (Key Elements C and D).

Students also observe the motion of thyme leaves suspended in vegetable oil. They represent the motion they observe in labeled drawings and identify the relationships among the components of the set-up (Key Elements A and B). Students make modifications to their initial experimental design, and then revise their diagrams based on new information about what causes Earth's plates to move (Key Element D). Students present their diagrams to the class and then discuss the strengths and limitations of each diagram for explaining the movement of Earth's plates (Key Element E).

Practice 3: Planning and Carrying out Investigations

The science practice of planning and carrying out investigations is illustrated in all four of the vignettes in this grade band.

Key Elements of Planning and Carrying out Investigations in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Identify what evidence is required to answer a scientific question	X	X	X	X
B. Design different types of investigations (e.g., observational, experimental) to provide valid and reliable data that can be used as evidence to answer different types of scientific questions (e.g., descriptive, relational, causal)	X	X	X	X
C. Carefully and systematically implement an investigation (e.g., make observations/measurements, manipulate/control variables, record data) consistent with the design of the investigation	X	X	X	X
D. Revise the design of an investigation as necessary based on preliminary findings or problems that arise with the initial design and/or procedures				X

All four vignettes demonstrate opportunities for students to identify what evidence is required to answer their scientific questions and design investigations to provide data that can be used as evidence (Key Elements A and B). In the LS vignette, students design experiments focused on factors that cause mutations. Students in the PHY vignette design investigations to help them answer their research questions about waves. In the ESS vignette, students plan investigations to determine the effect of heat on oil samples, using these data to help explain the movement of Earths' plates. Students in the CHEM vignette design investigations to determine how temperature and the size of a solid particle affect the rate of a reaction, and then make revisions to the design of their investigations based on problems they encounter during a trial run (Key Element D). Students in all four vignettes then carefully and systematically implement the investigations they planned (Key Element C).

Practice 4: Analyzing and Interpreting Data

The science practice of analyzing and interpreting data is illustrated in three of the vignettes in this grade band.

Key Elements of Analyzing and Interpreting Data in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Construct a data display (tabular, graphical) that facilitates analysis for answering the question being examined	X		X	X
B. Systematically compare data from multiple trials or measurements for consistency (within and/or across groups of students) to consider potential sources of error in data collection and/or identify anomalous cases	X		X	X
C. Analyze the data using grade-appropriate mathematical/statistical techniques to identify patterns, trends, and relationships			X	
D. Consider the limitations of data (e.g., missing data, measurement error) and the implications for the analysis and interpreting results	X		X	
E. Interpret (describe the meaning and relevance of) the results of the analyses for the question being examined			X	X

Students in the CHEM vignette construct data tables so that they can compare data from multiple experimental trials (Key Elements A and B). They also interpret the meaning of their data, considering what the water temperature and fizz-time measurements tell them about the reaction rate (Key Element E).

Students in the PHY vignette develop data tables to record frequency, wavelength, time, and speed of waves moving through a spring (Key Element A). They also graph their data (Key Element A) to help them make sense of it and examine any mathematical relationships (Key Element C). Students then compare their results to those of other groups for consistency (Key Element B) and interpret their data to determine that wavelength can be expressed as wave speed divided by frequency (Key Element E). Each group then presents their findings to the class, and the teacher prompts them to consider possible sources of error that could have affected their measurements (Key Element B).

In the LS vignette, students record data from their mutation-factors experiments in a chart, noting differences among the various trials (Key Element A). In cases where the results are not as expected, students think about modifications to their experiments that could address potential errors (Key Element B), as well as how errors in their data might impact the analysis and interpretation of their results (Key Element D).

Practice 5: Using Mathematics and Computational Thinking

The science practice of using mathematics and computational thinking is illustrated in three of the vignettes in this grade band.

Key Elements of Using Mathematics and Computational Thinking in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Use mathematics and computational thinking to develop and then use models in order to explore a phenomenon (e.g., determine a mathematical relationship to represent a phenomenon, develop a computational simulation to explore a phenomenon)	X			
B. Use mathematics and computational thinking in data collection (e.g., create an algorithmic procedure for data collection, determine criteria for sampling cases and programming a computer to identify all cases that meet the criteria)			X	X
C. Select and use appropriate mathematical/statistical/ computational techniques to organize and analyze data (e.g., determining the best measure of central tendency, examining variation in data, developing a fit line, developing rules for organizing data to make patterns evident)			X	
D. Use mathematical or computational models to generate evidence to support a claim when constructing explanations or engaging in argument from evidence				

Students in the LS vignette use models (Punnett squares) to explore how traits are determined in pea plants (Key Element A), including flower color, plant height, and seed shape. Students in the CHEM vignette develop algorithmic data collection plans to investigate the effect of water temperature or tablet size on the rate of a reaction (Key Element B).

The PHY vignette illustrates two opportunities for students to engage in the practice of mathematics and computational thinking. Students generate a set of procedures that allows them to iterate through different values of the independent variable to better understand the relationships among wavelength, wave frequency, and wave speed (Key Element B). They then conduct a graphical analysis to determine the mathematical relationships among these three factors (Key Element C).

Practice 6: Constructing Explanations

The science practice of constructing explanations is illustrated in three of the vignettes in this grade band.

Key Elements of Constructing Explanations in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Develop a line of reasoning using valid, reliable, and sufficient data as evidence, as well as existing scientific knowledge (e.g., ideas, models, theories) to support a claim	X		X	X
B. Revise explanations based on new evidence and existing scientific knowledge (e.g., ideas, models, theories)				X
C. When appropriate, seek out and use multiple sources of evidence to support a claim accounting for similar or sets of phenomena				X

The LS, PHY, and CHEM vignettes provide examples of opportunities for students to develop a line of reasoning to support a claim (Key Element A). In the LS vignette, students use evidence from the experiments they designed and implemented to support claims about factors that cause mutations. Similarly, students in the CHEM vignette use evidence from the experiments they designed and implemented to support claims about whether temperature and/or particle size affect reaction rate. In the PHY vignette, students support their conclusions about waves with data they collected in their investigations.

Other key elements of constructing explanations also play out in the CHEM vignette. Students revise their initial explanations based on new evidence that is presented (Key Element B). Students also draw upon multiple sources of evidence to support their claims about factors that affect reaction rates, including the experiments they conducted and information that they had learned previously (Key Element C).

Practice 7: Engaging in Argument from Evidence

The science practice of engaging in argument from evidence is illustrated in three of the vignettes in this grade band.

Key Elements of Engaging in Argument from Evidence in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
Developing Arguments				
A. Determine what evidence, including pertinent details about design, implementation, analysis, might persuade an audience about a model/explanation		X	X	
B. Provide, verbally or in writing, a reasoned justification to support or critique a model/explanation using valid, reliable, and sufficient evidence		X	X	
C. Evaluate and articulate the strengths and weaknesses of competing models/explanations	X	X		
D. Construct a persuasive case (in writing or verbally) for an intended audience for the best model/explanation for a phenomenon		X	X	
Critiquing Arguments				
E. Pose and respond to questions that elicit pertinent details about the important aspects of an argument, including pertinent details about the research design, implementation, analysis, evidence, and reasoning	X	X	X	
F. Use scientific reasoning and evidence to critique an argument, communicating this critique verbally and/or in writing	X	X	X	
G. When providing a critique of an argument, describe, verbally or in writing, what evidence is needed to further determine the validity of a claim	X			
H. Compare and critique multiple arguments on the same topic for whether they use similar evidence and/or differ in their interpretation of the evidence			X	
I. Respectfully provide and respond to critiques by citing relevant evidence	X	X	X	

The practice of engaging in argument from evidence is composed of two parts: developing arguments and critiquing arguments. Students have opportunities to both develop and critique arguments in three of the four vignettes in this grade band (LS, ESS, and PHY).

In the LS vignette, students review one group's experimental results and individually construct explanations about factors that can cause mutations. Because there is some variation in these individual explanations, the teacher divides students into group to evaluate and discuss the strengths and weaknesses of each (Key Element C). Students also develop written critiques of other groups' explanations about factors that can cause mutations (Key Elements E and F), and provide suggestions about what evidence would be needed to further support the explanations (Key Element G).

Students in the ESS vignette develop arguments for how Earth's plates move. Each group uses a poster session format to present their diagrams depicting plate movement to the class (Key Element D). Students describe their diagrams, and provide a rationale for the components they included (Key Elements A and B). During these presentations, students take notes about strengths and limitations they perceive in other groups' models (Key Element C). Students then verbally pose questions to their classmates about their arguments (Key Elements E and F), and each group is given the opportunity to respond to their classmates questions, citing evidence from their investigations and providing clarification about their experimental design to support their argument (Key Element I).

In the PHY vignette, students develop virtual presentations for one of the questions the class investigated related to wave phenomena (Key Element D). Their presentations include descriptions of their conclusions and how their data support those conclusions (Key Elements A and B). Students then review other groups' virtual presentations according to a set of provided guidelines (e.g., respectful, elicit clarification on experimental procedures or data analysis methods, alternative explanations considered and how the results may or may not refute those explanations) and post questions they have (Key Elements E and F). Students also note whether the arguments for each research question use similar evidence or differ in their interpretation of the evidence (Key Element H). The groups then respond in writing to the questions raised by their classmates, providing pertinent details related to such things as their design, analysis, and evidence cited to support their claims (Key Element I).

Practice 8: Obtaining, Evaluating, and Communicating Information

The science practice of obtaining, evaluating, and communicating information is illustrated in one of the vignettes in this grade band.

Key Elements of Obtaining, Evaluating, and Communicating Information in Grades 9–12 Vignettes

	Life Science	Earth and Space Science	Physics	Chemistry
A. Read and gather information from scientific and technical resources such as books, articles, tables, graphs, models, and community members relevant to the science-related question		X		
B. Evaluate the trustworthiness/credibility of one's own work and/or other sources according to their reliability, validity, consistency, logical coherence, lack of bias, and methodological strengths and weaknesses		X		
C. Distinguish observations from inference, and claims from evidence in one's own work and/or in other resources		X		
D. Compare and critique information obtained within one's own work and/or across multiple sources		X		
E. Summarize patterns, similarities, and differences in the information obtained from scientific sources		X		
F. Organize information in appropriate formats (e.g., written, multimedia, visual displays) obtained from one's own investigations and/or other sources in order to communicate it to various audiences		X		
G. Produce scientific and technical text and make oral presentations that integrate qualitative and/or quantitative information and appropriate representations, from one's own or others' scientific investigations, in order to clearly communicate the results		X		

At the beginning of the ESS vignette, students gather information about the motion of Earth's plates from a local geologist (Key Element A). They compare this new information to what they already understand about Earth's structure from previous class activities, readings, and experiences (Key Element D), considering the reliability of the various sources of information (Key Element B). Students then use all of this information to collaboratively develop a consensus diagram that illustrates how Earth's structure causes plate motion (Key Element E).

Later in the unit, students conduct an experiment in which they observe the movement of thyme leaves in oil. The teacher asks the students to discuss in their groups what they observe and what they can infer from the experiment. Students conclude that they are able to observe the movement of thyme leaves, which lets them infer the movement of the vegetable oil (Key Element C).

To conclude the unit, students revise their diagrams to more accurately depict the movement of Earth's plates. Each group uses a poster session format to present their diagrams to others in the class (Key Elements F and G).

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APPENDIX A

LITERATURE REVIEW PROCESS

LITERATURE REVIEW ON THE PRACTICES

A literature review was conducted to identify and summarize current research and practice-based knowledge focused on engaging students with the science and engineering practices described in the *Framework for K–12 Science Education* and the NGSS. A search utilizing the ERIC and Google scholar databases was conducted to find articles on the practices published since the release of the *Framework* in 2011.

Key words and phrases, such as *science and engineering practices*, *NGSS*, *models*, *argumentation*, and *explanations* were used in conjunction, and the initial search resulted in 76 empirical and practitioner-oriented articles and conference papers. These resources were reviewed more carefully to determine if the practices are described generally or if they are elaborated upon; resources that include only general descriptions of the practices were removed from the literature pool. Articles in practitioner journals that provide stand-alone lesson plans without any discussion of the practices were also excluded from the literature review. The remaining 47 articles were coded by:

1. Science and/or Engineering
2. Practices Addressed
3. Grade levels (K–5, 6–8, 9–12)
4. Nature of the Journal (practitioner-oriented, researcher)

Following the coding process, all articles were analyzed for whether a purpose for the practice is described—either a purpose related to the enterprise of science or a purpose in science education. In addition, each article was examined for whether it provides explicit guidance on "key features" of a practice, i.e., what is important for student to experience when engaging in the practice.

The following table displays all articles included in this literature review and the practices they address, followed by full citations for all articles. The majority of articles that passed the screening are from practitioner journals (35 articles). Most of the practitioner articles are intended for high school teachers (16), followed by middle school (12), and elementary (7). Frequently these practitioner articles focus on one or two of the practices, detailing how they play out in the classroom. The remaining 12 articles are either empirical or are products of conference presentations. A description of the practices culled from these articles was used as a foundation for the questions posed in the subsequent expert panel.

Literature Addressing the Science and Engineering Practices

	Practices							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Bell, Bricker, Tzou, Lee, & Van Horne, 2012								X
Berland & Hammer, 2012							X	
Braaten & Windschitl, 2011						X		
Brodsky & Falk, 2014							X	
Campbell, Neilson, & Oh, 2013		X						
Chen, Park, & Hand, 2013							X	
Chowning & Griswold, 2014							X	
Clary & Wandersee, 2013							X	
Covitt, Harris, & Anderson, 2013								X
Cunningham & Carlsen, 2014	X	X	X	X	X	X	X	X
Damico, 2014			X					
Dash & Hug, 2014				X				
Falk & Brodsky, 2013a		X						
Falk & Brodsky, 2013b						X	X	
Falk & Brodsky, 2014						X	X	
Ford, 2012							X	
Foster, Husman, & Mendoza, 2013		X						
Gotwals & Songer, 2013						X		
Gould, Sunbury, & Dussault, 2014				X				
Huff & Bybee, 2013							X	
Knight & Grymonpre, 2013							X	
Krajcik & Merritt, 2012		X						
Kraus, 2014				X	X			
Krell, zu Belzen, & Krüger, 2014		X						
Lachapelle, Sargianis, & Cunningham, 2013	X	X	X	X	X	X	X	X
Lee, Cite, & Hanuscin, 2014							X	
Lee, Quinn, & Valdés, 2013		X				X	X	X
Llewellyn, 2013							X	
Llewellyn & Rajesh, 2011							X	
Mayer, Damelin, & Krajcik, 2013		X						
Mayes & Koballa, 2012	X	X		X	X		X	X
McLaughlin, 2013				X				
McNeill, 2011						X	X	
Miele & Bennett, 2014	X		X					X
Milano, 2013	X	X	X	X	X	X	X	X
Miller, Rivet, Kastens, & Lyons, 2013		X						
Miranda & Hermann, 2013	X	X	X	X	X			X
Oh & Oh, 2013		X						
Osborne & Patterson, 2011						X	X	
Reiser, Berland, & Kenyon, 2012						X	X	
Rivet & Kastens, 2012		X						
Sampson, Enderle, & Grooms, 2013							X	
Smith, Molinaro, Lee, & Guzman-Alvarez, 2014				X				
Smith, 2014	X		X		X			X
Sneider, Stephenson, Schafer, & Flick, 2014					X			
Taylor, 2013							X	
Texley, 2014		X						
Windschitl & Thompson, 2013		X						
Total	**7**	**17**	**7**	**10**	**8**	**11**	**23**	**10**

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Kraus, R. (2014). Reflecting on data. *Science Teacher, 81*(8), 45–49.

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APPENDIX B

EXPERT PANEL PROCESS

Expert Panel

A months-long expert panel was conducted to "unpack" the science practices, identifying key aspects of the practices at different grade bands and areas of science. The expert panel was composed of individuals with backgrounds and experiences at different grade levels and content areas. In addition, panelists had varied levels of involvement with the NGSS, including some panelists who served on the writing team. The eight panelists collectively had the following expertise: university-level science educators, scientists, state and district science supervisors, and teachers. Some panelists had expertise in more than one of these areas.

The panel process involved four rounds of questions that were emailed to the panelists, each of whom submitted responses without knowledge of the other panelists' responses or even the identity of the other panelists. Questions in Rounds One and Two addressed four practices: constructing explanations; engaging in argument from evidence; obtaining, evaluating, and communicating information; and using mathematics and computational thinking. Rounds Three and Four focused on the remaining practices: developing and using models, asking questions, planning and carrying out investigations, and analyzing and interpreting data. Panelists were asked to complete a series of questions/tasks related to each practice including: (1) constructing a definition of the practice; (2) identifying the key elements of what students need to experience at various grade levels and in different science content areas that are essential for helping them master the practice; and (3) generating examples of what instruction "looks like" as student engage with the practice.

Constructing a Definition of the Practice

Panelists were provided with a draft description of each science practice drawn from the Framework, NGSS, and various articles collected as part of the literature review. They were asked to review the draft, make any revisions to the definition they deemed as necessary, and provide a rationale for any revisions they suggested. The definitions provide by each panelist was used as a lens to interpret their remaining responses to questions/tasks related to that practice.

The Next Generation Science Standards (NGSS) and various articles characterize the practice of modeling. From those sources, we have developed a definition. a. Use track changes to make any revisions to the definition that you think are necessary. b. Provide a rationale for the revisions that you made to the definition.

Sample Panel Task: Constructing a Definition of the Practice

Identifying the Key Elements of the Practice

For each science practice, panel members were asked to provide a detailed example of instruction engaging students in the practice as part of meeting an NGSS performance expectation or learning about a particular topic area. Panelists were then asked to identify the key elements of what students were doing in their description that are essential for helping students master that practice. In addition, panelists were asked to specify whether/how the key elements differed by grade band and science content area. The key elements offered by the panel, along with other key elements identified in the literature review, were compiled. In the subsequent round, panelists were asked to provide feedback on the set of compiled key elements, noting whether they: (a) agreed that the element is essential for helping students master the practice; (b) agreed that the element is essential for helping students master the practice if modified (providing the edits needed); or (c) disagreed that the element is essential for helping students master the practice. Panelists also had the opportunity to add key elements that were missing from the compiled list and to specify at which grade bands students should experience each of the listed elements.

Considering the revised list of key elements for asking questions that you have specified in this round (i.e., all of the elements you have agreed with, edited, or added), please provide the following at a grade band and content area of your choice: a. A detailed example of students asking questions that illustrates how students experience this practice at the selected grade band. Please be specific in your illustration. b. A description of how your example illustrates the key elements of asking questions.

Sample Panel Task: Identifying the Key Elements of the Practice

Generating Examples of Students Learning Science through Engaging with the Science Practices

Throughout the four rounds, panelist were asked to generate descriptive examples of instruction in order to operationalize what instruction would "look like" when student experience a particular practice. As noted previously, panelists provided descriptive examples in order to generate a list of key elements. In addition, panelists were asked to use the final list of key elements to provide a detailed example of students engaging with a science practice in order to illustrate what the practice looks like at a particular grade band and identify differences across grade bands.

Please select the NGSS performance expectation that you are most familiar with from the three options provided. a. What assumptions would you make about the relevant science content a typical student in this grade band should know prior to instruction on this performance expectation? b. What assumptions would you make about what a typical student in this grade band should be able to do in relation to the science practice of constructing explanations prior to instruction on this performance expectation? c. What would an observer in a classroom see students doing during instruction to prepare them to meet this performance expectation?

Sample Panel Task: Generating Examples of Students Learning Science through Engaging with the Science Practices