Guide to Science and Engineering Practices and Crosscutting Concepts







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Guide to Science and Engineering Practices and Crosscutting Concepts

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Introduction

Twig Science South Carolina takes the “little and often” approach to delivering the South Carolina College- and Career-Ready Science Standards’ Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs). They are fully embedded in the course, and you will introduce and return to them several times within each grade.

It is important that students know which SEP or CCC they are using to make sense of situations they encounter in science class. Teacher Editions signpost which SEPs and CCCs are developed in each lesson, alongside the relevant Disciplinary Core Ideas and Performance Expectations. We suggest you also create a classroom Science Tools poster to record each of the eight SEPs as they arise for the first time in each grade. Teacher Editions provide guidance on when to add each SEP to the poster, summarizing the connection between the SEP and the day’s learning.

Within the SCCCR Science Standards Framework there is a progression in how students are expected to apply the SEPs and CCCs, with separate expectations for grade bands K–2 and 3–5. However, you may push Grade 2 students further if you think they are able, for example, or go back to basics with Grade 4 students if they have not yet mastered the practice.

This guide contains a short summary of each SEP and CCC and why it is important. The progression of the SEP or CCC through each grade band is then discussed, with reference to the SCCCR Science Standards Framework and grade-specific, contextual examples from the Twig Science South Carolina program. Finally, there are some top tips for improving your teaching of each SEP and CCC.

Science and Engineering Practice 1—Asking Questions and Defining Problems

What Is SEP-1—Asking Questions and Defining Problems?

SEP-1 encourages students to ask relevant questions about the world they see, which can lead to scientific investigations to seek answers to those questions or to articulate an engineering or design problem that needs a solution.

Why Is SEP-1—Asking Questions and Defining Problems Important?

No employee will be able to compete with a machine that can process thousands of transactions in a minute. However, no machine can ask novel questions about the world around them or define an engineering problem where the solution involves several conflicting requirements. If your students are curious about what they see and hear and can translate this into coherent questions about the world, they will always be employable, no matter what jobs are available in the future.

Asking Questions

Good questions arise from careful observations, sometimes leading to new scientific theories and inventions. In 1945, the Raytheon engineer Percy Spencer noticed that the peanut bar in his pocket started to melt when he stood next to the radar set he was testing. He was motivated to ask, “Why is the candy in my peanut bar melting?” From this question, after a lot of investigation, Raytheon made the first microwave oven in 1946.

Defining Problems

Defining engineering problems is a little different. Instead of beginning with a question to investigate, students need to ask questions about a practical problem that needs to be solved. For example, NASA needed to design a new visor to be fitted to astronauts’ helmets for space travel. It identified two constraints quite quickly:

- The visor could not be made of glass as it was too brittle.
- The visor could not be too expensive to make.

In addition, NASA astronauts said they wanted a lightweight visor that did not scratch easily. These were the success criteria. The criteria and constraints led to questions about whether plastic, a lightweight material, might be the right material to make the visor. NASA was then able to define the problem: How do you make a plastic visor that does not scratch? The solution, after 10 years of research, was a coating on the plastic visor—light, tough, and scratch resistant. Today, all glasses have this coating on the lens and last 10 times longer than they used to.



We cannot expect students to be experts in asking scientific questions and defining engineering problems without training. Their training starts the moment they walk into your classroom.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Asking questions and defining problems in K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested.

- *Ask questions based on observations to find more information about the natural and/or designed world(s).*
- *Ask and/or identify questions that can be answered by an investigation.*
- *Define a simple problem that can be solved through the development of a new or improved object or tool.*

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 3, Lesson 5
In this module, students progress to using data to generate questions. The class has been recording weather data over a long period of time using weather symbols. It is now given four days' data for a different city and supported to ask questions about the weather in that city, which can be answered using the data. Using a familiar context reduces the cognitive load of the task and means students can concentrate on thinking up their own questions about the new information, rather than trying to understand the way the data is presented.

Grade 1
Module 1: Museum of Leafology
Driving Question 1, Lesson 3
After watching a video about amazing plants (something tangible they can see), students are prompted to come up with their own questions about plants—some of which they could try to answer when they explore outside. Some students will not be used to the open-ended nature of this task, so the Teacher Edition provides some example questions to help you model the kinds of questions that scientists ask, including "How many different kinds of plants are there?" and "Why do plants look so different to each other?" Provide many opportunities to ask scientific questions over the year and your students will start to get the idea.

Grade 2
Module 2: Master of Materials
Driving Question 2, Lesson 7

Students are investigating the differences between ice and water. Students handle the materials and are given time to think about what they might want to find out by investigating the materials further using sight and touch. You can support the process by modeling the type of questions that can be investigated to find an answer. Examples are provided in the Teacher Edition, such as “What happens when you put ice in a glass of hot water?” and “How can you make an ice cube get smaller or larger?”

Grade 2
Module 4: A Garden for Life
Driving Question 4, Lesson 2



Here, students are supported to define problems. They examine text in their Twig Books and identify the problem (pollinators are disappearing) and the suggested solution (design a garden that encourages pollinators). At this grade, being able to spot a problem in a specific piece of content lays the foundation for progression in later grades, when students will need to think more deeply about defining problems by asking questions to obtain data and information that may limit possible solutions.

Grades 3–5

Asking questions in Grades 3–5 builds on experiences from Grades K–2 and progresses to asking qualitative questions about investigation results and determining cause-and-effect relationships. It may be useful to prompt students by providing a sentence frame on the board (e.g., How does…affect…?), which can help them link two variables in a question. Do not be afraid to return to the basics from Grades K–2 if students are still struggling with the concept of generating questions about what they observe. Defining problems in Grades 3–5 builds on experiences from Grades K–2 by requiring students to begin to identify criteria and constraints that a possible solution must meet.

Asking questions and defining problems in 3–5 builds on K–2 experiences and progresses to specifying qualitative relationships.

- *Ask questions about what would happen if a variable is changed.*
- *Identify scientific (testable) and non-scientific (non-testable) questions.*
- *Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.*
- *Use prior knowledge to describe problems that can be solved.*
- *Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.*

—SCCCR Science Standards Framework

Grade 3
Module 1: The Ultimate Playground
Driving Question 4, Lessons 2 and 3
These lessons help students make the link between asking questions and determining cause-and-effect relationships during an investigation. Students are given magnets and a range of items they could test for magnetism. After having time to explore the materials, they come up with three questions they could investigate.

From Grade 3, you should encourage more discipline in asking questions that can be tested (answered by an investigation). As well as selecting a question to investigate, the added dimension is the cause (what they will test, i.e., the variable they will change) and the results of the test (the effect). Model questions are provided if students don't have many questions, such as "How does distance affect the pull of a magnet?" The cause is moving the magnet further away from the iron filings and the effect is that the iron filings move less as a result. Not all students will understand cause and effect first time, so model it for those that need extra help and come back to it later in the grade.

Grade 4
Module 1: Egg Racers
Driving Question 3, Lesson 1
Students observe two balls of the same size crashing into each other. They then think about what questions they could ask about what they have seen. As a result of a class-led discussion, students design a fair test to investigate one of the questions they have come up

with themselves. They are encouraged to change just one variable, such as the size of the ball, and suggest what might happen.

Grade 5
Module 2: Yellowstone—Uncovered
Driving Question 1, Lesson 2
Students set up their own investigations into what plants need to grow. It is helpful in this grade band to start investigations by asking students what they wonder about a subject and then reframing their wonderings as questions that they could investigate. Students are asked:

- If I am testing whether plants need sunlight to grow, how could I frame this as a question that I could investigate?

It may be useful to prompt students by providing a sentence frame on the board. In this case:

- Do plants need _____ to grow?

Remember, the focus here is asking questions it would be possible to investigate. Later in the lesson, students are asked about the one thing that they will change in their investigation that will help them answer their question and what they will keep the same to make it a fair test.

Top Tips

Tip 1: Embed the habit early in the year.

All students have an endless supply of science-based questions if we just allow them time to be curious.

In the early Twig Science South Carolina modules, encourage students to come up with their own questions as often as possible. You might prompt:

- What questions do you have about…?
- What does it make you wonder about…?
- Can you think of a different question you would like to investigate?

Don't worry about how relevant or productive students' own questions are until later in the year, and remember that you don't always need to know the answer to every question that students come up with. The important thing is to establish the habit: scientists ask questions and look for answers.

If you have a little time at the end of a lesson or at the end of the day, you could use standard routines like Turn and Talk, Stronger and Clearer Each Time, or the Questioning Formulation Technique (QFT) to generate questions from the class about what they have seen or what they have been investigating. Remember to be encouraging, don't over praise, and make sure everyone has an equal chance of speaking.

Tip 2: Practice sorting questions regularly.

Once you have developed the culture of asking science-based questions in your classroom, ask students to think about those that can be investigated and those that cannot. This becomes particularly important in Grades 3–5. If students don't understand what a scientific question is, give them examples in a familiar context. For example, "Should I eat less chocolate?" is not a scientific question, but "What brand of chocolate bar contains the most sugar?" is because it can be investigated. Here are some examples:

Question Cannot Be Investigated	Question Can Be Investigated
What would it feel like to be in an earthquake?	What was the percentage chance of being killed by an earthquake last year in South Carolina?
What might have destroyed those buildings?	Is it possible to make a building that can survive earthquakes better than others?
What would you do during an earthquake?	Do some parts of the world have more earthquakes than others?
Does Earth open up during an earthquake?	Do all earthquakes damage houses?

Tip 3. Model asking questions about the results of an investigation.

In all grades, students need to use their observations to frame questions that can be answered by investigation. In later grades, they need to ask questions about the results of investigations in order to clarify or challenge arguments. The best way to develop this skill is to model it yourself with the class, demonstrating your own curiosity and using simple sentence frames. For example, ask:

- I wonder if...?
- What happens if we change...?
- What could you do differently to alter the outcome of the experiment? [Students who wonder what would happen, for example, if they were to push a ball with more or less force, are starting to understand that changing variables in investigations will often affect the results of the experiment.]
- Why do you think there is this pattern in the data? What might cause this pattern?
- This result was not what we expected. What question could we investigate to see if our idea was correct?

Practice this many times over the year and your students will start to be able to formulate questions independently.

Tip 4: Help students visualize the engineering problem they are trying to solve.

To help students visualize the problem, try asking, “What happened next?” For example, Grade 4 students will design an earthquake-proof structure. Asking students to visualize what is going to happen to the building in the film helps them concentrate on the problem they are trying to solve. The criteria for success, constraints, and other parts of the engineering standards can come later.

Science and Engineering Practice 2—Developing and Using Models

What Is SEP-2—Developing and Using Models?

In science, models are generally representations of systems or parts of systems, and they allow scientists to investigate or to communicate their ideas about phenomena. In engineering, models can be used at different phases in the design cycle—to develop, test, or refine a design, or to communicate design ideas to others.

Why Is SEP-2—Developing and Using Models Important?

Throughout the SCCCR Science Standards Framework, modeling serves a number of purposes that are critical to students' learning and communicating ideas. In science, students use models such as interactives, diagrams, manipulatives, or role-playing in order to investigate phenomena that would be difficult to investigate firsthand. This may be because it is not possible to bring a particular system into the classroom, it is too big or small, or changes occur too quickly or slowly to observe directly. In the science classroom, for example, we do not have the benefit of being able to observe particle collisions taking place as a sound wave moves across a room, the arrangement of the objects that make up our solar system, or the changes in population dynamics in an ecosystem over the last 25 years.



Models allow students to investigate these (and many, many other) phenomena, and to gather key evidence to support the scientific explanations behind them. In addition, models allow students (and scientists) to make predictions about future events and relationships. As students develop or deliver their explanations, models allow them to communicate the ideas they have constructed through investigation. For example, after investigating the relationship between the structures of pollinators and the plants that they pollinate, students can develop models to communicate their understanding of these structure/function relationships. Students who pursue careers in science will find modeling serves similar key roles, allowing them to investigate, predict, and communicate their ideas.

In SCCCR Science Standards engineering activities, modeling serves an equally critical role as in science. In particular, because students likely will not have access to the resources to

build “real” inventions from their designs, models serve as important representations that can easily be built and tested in the classroom. For example, students won’t have access to the various metals, electronics, and tools needed to create a real prosthetic hand, but they can create and test a prototype using common classroom materials. Similarly, engineers build prototypes—models of their designs—to test and look for possible flaws before they build with the final materials. Students who pursue engineering will find that the modeling skills they develop throughout their school years can be built upon and will serve them well in their careers.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.

- *Distinguish between a model and the actual object, process, and/or events the model represents.*
- *Compare models to identify common features and differences.*
- *Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s).*
- *Develop a simple model based on evidence to represent a proposed object or tool.*

—SCCCR Science Standards Framework

Grade K
Module 1: My Big Nature Adventure
Driving Question 5, Lesson 4
Having investigated the relationships between organisms and non-living things in different environments, students develop models to communicate their ideas about these relationships. To begin, students view a collection of images from a grassland environment and draw a connection (literally and figuratively) between each living thing and something it needs to survive. For example, they might draw a connection between the lion and the zebra (the zebra is food for the lion), or between the water and any one of the animals (which need water to drink). Then, students draw a model showing one of the relationships from the matching portion of the activity. At the end of the lesson, the teacher refers to the scientific practice of Developing and Using Models and discusses some of the ways in which scientists use models to investigate or communicate ideas.

Grade 1
Module 1: Museum of Leafology
Driving Question 6, Lesson 5
At this point, students have investigated various plant structures that work to protect plants. In previous lessons, students have defined engineering problems that they believe could be solved using inspiration from plants and worked in pairs to draw diagrams of design solutions inspired by plant structures. In this lesson, students build 3-D models of their design solutions. Students share their models with the class and discuss how they might address design problems.

Grade 2
Module 4: A Garden for Life
Driving Question 3, Lesson 9
In previous lessons, students were tasked with developing models showing pollinator/flower relationships. They used materials to create their 3-D models, carefully choosing each material so that it clearly connected to the structure it represented. In this lesson, students write reports about their models. They describe what structure each part represents and why they chose the materials they did to represent each structure. Their reports and models together offer an opportunity for students to communicate their learning about pollinator/flower relationships and about plant and animal structures and their functions. Students will present their reports and models to their peers in the following lesson.

Grades 3–5

Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.

- *Identify limitations of models.*
- *Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.*
- *Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution.*
- *Develop and/or use models to describe and/or predict phenomena.*
- *Develop a diagram or simple physical prototype to convey a proposed object, tool, or process.*
- *Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.*

—SCCCR Science Standards Framework

Grade 3
Module 2: Welcome to the Biodome
Driving Question 1, Lesson 8

This lesson is one of a series in which students are introduced to and develop models of the life cycles of different organisms. Students observe a video about the splash tetra fish. They synthesize what they observe by developing diagrams (models) showing their ideas about the life cycle of the splash tetra, comparing it to that of other organisms whose life cycles they have investigated and modeled.

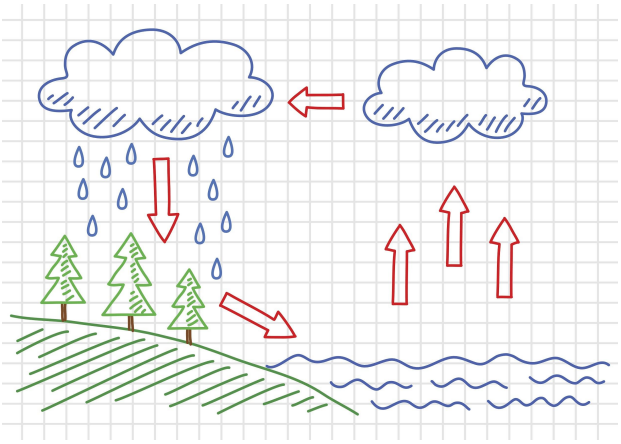
Grade 4
Module 5: Super Survivors
Driving Question 4, Lesson 2
Students demonstrate their learning through building models to show their ideas about how we see. Students work in teams to each design and build a 3-D model that includes an object, a light source, external and internal body structures involved in sight (eyes, nerves, brain), and the path of light. Teams choose from a variety of materials for their models and, as they build, the teacher presses students to explain their choice of materials by connecting to the function of each structure involved in sight. Students share their models with the class in a gallery walk and give and receive peer feedback. Student work is evaluated using a rubric.

Grade 5
Module 2: Yellowstone—Uncovered
Driving Question 6, Lesson 1
Throughout the module, students use models both to investigate ideas and to demonstrate their learning. In this lesson, students use an interactive model to investigate the long-term effects of removing an organism from an ecosystem and of adding a non-native species. This model allows students to observe a phenomenon in a matter of minutes that would take years in the real world: when a species is removed from an ecosystem, or a non-native species is added, there is a cascading effect on other organisms in the ecosystem. Students gather and graph data collected from their observations of the model and discuss their findings as a class.

Top Tips

Tip 1: Leverage models for assessment.

A great way to assess how well students understand, for example, the relationships between parts in a system, or a cause-and-effect phenomenon, is to ask them to develop models to show their ideas. You can ask students to continually revise models throughout a learning cycle and use each stage of the model as a



formative assessment to gauge students' growing understanding. Or you can have students use models as part of a summative assessment, utilizing a rubric to assess learning against learning goals.

Tip 2: Model often.

As mentioned, models are of utmost importance in science and engineering, and for good reason: they allow scientists (and students) to investigate or to communicate ideas about phenomena that may be difficult to observe directly. Any time you are discussing a phenomenon with students, look for opportunities to develop models to allow students to investigate and gather evidence or to share the ideas that they are constructing. If a student seems to be struggling with a concept, encourage them to develop a model to help them organize their ideas, or work together to develop one. If students are being asked to present ideas that they have constructed about the relationships between parts in a system, for example, ask them to develop models to accompany their presentations. These models then become useful formative assessment tools and also help listeners better understand the concepts being communicated. Models can be helpful outside of the science classroom too! Look for opportunities to leverage models for learning as you teach other disciplines.

Tip 3: Have students identify when models will be useful.

Early in the year, introduce modeling as a useful practice for investigation and evidence-gathering or for communicating ideas. Allow students many opportunities to model. (There are many opportunities throughout the Twig program, along with guidance and suggestions on how to build them.) Then, begin to ask students to identify when a model would be appropriate or useful. You might say, "We can't investigate that phenomenon directly—it's just too big [or too small, or moves too slowly or quickly]. What tool could we use that would allow us to investigate further?"

Science and Engineering Practice 3—Planning and Carrying out Investigations

What Is SEP-3—Planning and Carrying Out Investigations?

SEP-3 challenges students to plan and carry out their own investigations. Rather than being told which steps to take to answer a scientific question or how to solve a problem, students begin to think like scientists or engineers as they question the world around them.

Why Is SEP-3—Planning and Carrying Out Investigations Important?

Learning to plan and carry out investigations is an important problem-solving skill for students of all levels and in all disciplines to master. As they grow in confidence, they will begin to question things beyond the classroom and realize that they have the ability to discover the answers themselves. While they progress through the various grade levels, students are given more responsibilities as they identify variables and controls in an experiment, collect and analyze data, and question their own hypotheses.

In 1952, Rosalind Franklin and her team in the United Kingdom planned and carried out careful investigations on the structure of DNA. They used X-rays to photograph DNA, and the data they produced (especially Photograph 51) helped them claim that DNA was a double helix. This evidence was key in working out the structure and function of DNA the following year.



Mastering such skills as problem solving, creativity, and collaboration in the context of investigations will prepare students for success as they enter college and the workforce, regardless of their chosen areas of study.

Planning Investigations

A solid plan is integral to any success. Students begin with a testable question and determine how to carry out the experiment or test an engineering solution. They learn to state their claim, predict the results, and develop a procedure that produces the right evidence. They decide how they will collect data and how it will be measured and recorded. Does the data even matter? As they progress through the later grades, they will delve deeper into the science of their experiments. Is there a control to compare the test data with? What are the dependent and independent variables? Is it a fair test? Can the data collected be used to support a claim or choose the best solution to a problem?

Students will also act as engineers as they begin to test multiple solutions designed to solve specific problems. Their investigations are essential in producing evidence that helps them decide on best solutions and how to revise their designs if necessary.

Carrying Out Investigations

Once a plan is in place, students will carry out their investigations. Often, it will quickly become obvious that an original plan will not work as intended. As students plan and carry out multiple experiments, these skills will begin to become systematic and a natural way of thinking. They will learn that things often need to be changed and plans revised in order to answer questions posed or to collect the data sought. A major learning moment is when a student discovers that their original hypothesis was wrong and they have to come up with a new idea. Through all of this, students hone their reasoning and processing skills, become skilled questioners, and become more curious about the world in which they live.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

In Grades K–2, most of students' experiment planning will be based on prior experiences. Students know that toy cars move when "driven" with a hand, but they do not yet know why. The investigations are simple and straightforward, yet student driven. This level lays the framework for students to begin questioning and analyzing basic tasks.

Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.

- *With guidance, plan and conduct an investigation in collaboration with peers (for K).*
- *Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question.*
- *Evaluate different ways of observing and/or measuring a phenomenon to determine which way can answer a question.*
- *Make observations (firsthand or from media) and/or measurements to collect data that can be used to make comparisons.*
- *Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal.*
- *Make predictions based on prior experiences.*

—SCCCR Science Standards Framework

Kindergarten
Module 2: Marble Run Engineer
Driving Question 1, Lesson 1
Students are given a set of objects and the task of determining how the objects move. Through play-like exploration, they determine how to make the objects begin to move, keep moving, and stop. They are introduced to the concepts of push and pull as they move the objects toward and away from themselves. They begin to analyze which objects are harder to move and why, as well as which objects can move without much help.

Grade 1
Module 3: Shadow Town
Driving Question 1, Lesson 2
Students are taken outside to explore their own shadows. Where do they come from? What can be learned from looking at the direction and length of a shadow? Students are also asked if they can run away from their shadows. Through experimentation and scientific investigation, students come up with the answers to these questions and more.

Grade 2
Module 2: Master of Materials
Driving Question 5, Lessons 4–9
Students are given the task of planning, drawing, and building two bridges, one to cross a wide river and one which allows tall ships underneath it. In teams, they plan and design their bridges and then build them one after the other using the same materials but a different design. Students check that their finished bridges solve the problem, test to see which is the strongest, and determine which materials are the best for building these structures.

Grades 3–5

In Grades 3–5, the focus shifts to controlling variables to produce data that answers scientific questions or tests designs. At this level, students are expected to identify the variables to be tested and those that should be kept the same (controlled). They begin to understand that experiments must be repeated multiple times in order for data to be accepted as reliable. They also learn to design multiple solutions to a problem and test them to see which one is the most successful.

Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K– 2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions.

- *Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.*

- *Evaluate appropriate methods and/or tools for collecting data.*
- *Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.*
- *Make predictions about what would happen if a variable changes.*
- *Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.*

—SCCCR Science Standards Framework

Grade 3
Module 1: The Ultimate Playground
Driving Question 1, Lesson 3
Student pairs act as engineers to test out a new roller-coaster track. Their challenge is to investigate various forces as they move a ball along a series of tracks. They may use pushes and/or pulls, or rely on some other force to complete the task. Student pairs must determine the different forces required to move the ball along different track arrangements and track types.

Grade 4
Module 3: Time-Traveling Tour Guides
Driving Question 3, Lesson 2
Teams design stream-tray investigations into the effects of different variables on the interaction between water and land. Students choose a single variable, such as mountain size, boulders, or water volume, and design an investigation into how changing that variable affects the stream that they will create. They determine what type of data they will collect and how they will measure it to illustrate the changes to the stream.

Grade 5
Module 1: Matter Mysteries Hotline
Driving Question 1, Lesson 6
Teams examine various materials to determine which would be the best suited for creating an outdoor explorer backpack. Students run a series of fair tests to determine some basic properties of various materials. The focus is on designing a controlled experiment that tests only one variable at a time. Students take the information that they record and determine which of the tested materials would make the best backpack.

Top Tips

Tip 1: Practice questioning.

The question is possibly the most important part of a scientific experiment. Encourage the students to question things. More importantly, expect them to seek out the answers (and not just ask you!). If they do ask you, use the Socratic questioning technique until they come

upon the answers themselves. Allow them to do the discovering. Once they understand the art of questioning, you will find that they start to question everything!

Tip 2: Build scientific confidence.

Many students have the misconception that they are not "good" at science or that science is too hard. Start small and let them celebrate their scientific successes. Choose a "Scientist of the Week" to act as the teacher's lab assistant, send home award certificates recognizing scientific achievements, or simply send a note or text to parents praising what the students are doing. Help the students to realize that they are constantly conducting science experiments every day of their lives. Think of a simple real-life example that fits into their world and let it grow.

Tip 3: Establish routines.

Establish a routine for distributing lab materials early in the school year. Will the students pick up their materials from a central supplies station? Will one student retrieve the supplies? Will things be passed out to the students? Also, determine how clean-up will take place. Consider assigning roles to each member of a team: one student to return the lab supplies, one to wipe the table, one to pick up materials that have fallen on the floor, and one to be in charge of any written work—or whichever roles work in your classroom and minimize wasted time. Routine will also reduce the likelihood of classroom and laboratory accidents. Safety is key in every science lab!

Tip 4: Prepare to be flexible.

While it is important to maintain classroom control, it is also important to be open to students' thoughts, ideas, and questions, which is the spirit of the SCCCR Science Standards Framework. Avoid telling the students each step that they should take in an experiment. If they come up with an investigation that you have not thought of and it is safe and feasible, let them give it a try! Be willing to modify your original plans. You might be surprised by the results!

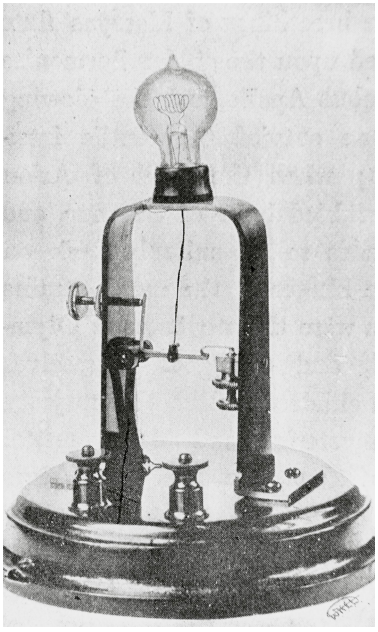
Science and Engineering Practice 4—Analyzing and Interpreting Data

What Is SEP-4—Analyzing and Interpreting Data?

One of the main cornerstones of science is evidence—data collected by scientists. In real life, the data scientists collect is usually messy and unclear until it is organized in such a way that reveals patterns and relationships. SEP-4 involves students looking for patterns and finding meaning from data that they have been given or that they have collected from their own investigations. It also helps prepare students for using data to assess and predict the performance of design solutions, as engineers do.

Why Is SEP-4—Analyzing and Interpreting Data Important?

Scientific explanations are never based on feelings or guesses, but on evidence. The answers to credible scientific questions are based on good data designed to prove a point. All those who think and work scientifically aim to analyze and interpret data in a fair and concise way that will reveal patterns and relationships that can provide meaning and relevance to what they have observed. This analysis and interpretation can then be used as evidence when being communicated to others.



People like Thomas Edison or Louis Pasteur were able to make important engineering and scientific advances because they knew how to record, analyze, and interpret data. Edison did not just stumble on a way to bring efficient, practical light bulbs to the masses: he finally found a solution after carefully analyzing his hundreds (some say thousands) of failed attempts. In the same manner, Pasteur developed his germ theory after carefully collecting and interpreting data. Without the data to back up his claims, his ideas would have held no merit. This process of analyzing and interpreting data is foundational to science. Students are more likely to enjoy science when these skills are developed starting at an early age.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

In Grades K–2 the data that tends to be analyzed and interpreted is qualitative and comes from simple observations. Students can observe things like changes in a plant's height over time, changes in weather, or differences in animals' fur. These observations can be organized in simple ways that help students to use the data to answer questions and make sense of what they are seeing. In these grades, it is important for students to begin to see the power of data to answer scientific questions and the importance of having evidence to back up those answers.

Analyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations.

- *Record information (observations, thoughts, and ideas).*
- *Use and share pictures, drawings, and/or writings of observations.*
- *Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems.*
- *Compare predictions (based on prior experiences) to what occurred (observable events).*
- *Analyze data from tests of an object or tool to determine if it works as intended.*

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 3, Lesson 5
Students look at data they have been collecting daily about the weather. They are prompted to think about what weather-related questions they could answer by using their data. Students then set out to look for patterns in their data that would answer their questions. They may ask something like, "How many times did the weather change?" By using their own data to answer their own questions, students begin to see the power of data and data analysis as a valuable science practice.

Grade 1
Module 1: Museum of Leafology
Driving Question 1, Lesson 4
This lesson gives students an introduction to making observations. Students begin by observing a seed and soil, before planting that seed and predicting what will happen. They organize their observations in a chart that they will add to over the the following few weeks. These observations will eventually allow them to describe patterns and see change over time.

Grade 2

Module 1: My Journey West
Driving Question 2, Lesson 8
Students take their observations about melting and freezing from the previous lesson and organize them into a chart, before using the chart to answer their scientific questions. They watch a video that should validate their conclusions and help them see that their data-gathering helped them correctly answer scientific questions. Finally, students discuss the merits of their data chart as a tool for communicating observations to people who did not participate in the experiment themselves. They see the value of recording observations as a way to draw conclusions and communicate their results.

Grades 3–5

In Grades 3–5 students build on their data-collecting and recording skills from Grades K–2 and begin to focus on quantitative strategies for collecting and displaying data. They use their newly acquired math skills to display data using bar graphs, pictographs, and/or pie charts. The complexity of their data displays should grow throughout the 3–5 grade span as their math skills grow. These displays are then used to look for patterns and relationships, often by prompting students to use their displays to answer specific questions.

Analyzing data in 3–5 builds on K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.

- *Represent data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships.*
- *Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation.*
- *Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.*
- *Analyze data to refine a problem statement or the design of a proposed object, tool, or process.*
- *Use data to evaluate and refine design solutions.*

—SCCCR Science Standards Framework

Grade 3
Module 4: Weather Warning HQ
Driving Question 1, Lesson 8
Students analyze three bar graphs, created in previous lessons, in order to answer the Driving Question: “What are the weather patterns in our local region and how do they change between seasons?” While previous lessons focused on gathering and displaying data, students are now tasked with analyzing data to draw conclusions about local weather

patterns. They are then asked to use their conclusions as evidence while presenting an answer to the Driving Question.

Grade 4
Module 4: Earthquake Engineering
Driving Question 2, Lesson 3
Students gather data about various earthquakes and enter it into the Earth Explorer interactive. This data-representation tool allows them to interpret the data, use it to make sense of patterns in earthquake locations, and draw a logical conclusion about where earthquakes occur. Students then conclude that the majority of Earth's earthquakes occur in bands along plate boundaries.

Grade 5
Module 4: Galactic Guidebook
Driving Question 1, Lesson 3
Students use evidence to work out if there is a pattern to the length of daylight hours throughout the year. As a class, they consider parameters for data collection and make decisions about how to display data. Students then use an online interactive tool to collect their own data, before creating bar graphs to find patterns. Students are led to see that the visual representation of the data (in this case a bar graph) was useful in seeing the pattern.

Top Tips

Tip 1: Be mindful of the math.

Each grade level has unique math standards that deal with data collection and representation. SEP-4 does not ask students to do more complicated analysis and representation of data than they are already doing in math at their grade level. If we ask them to analyze data using mathematical skills that they do not yet possess, then frustration may result. Dealing with this may be easier for teachers in self-contained classrooms who are teaching both math and science. For teachers who only teach science, this may mean connecting with the math teacher in order to become more aware of what their students know and do not know.

Tip 2: Practice makes perfect.

Even if you only cover data-representation skills that students are familiar with, they can struggle if it is not in a "math" context. Students will still need to see regular demonstrations of how to represent, analyze, and interpret data. For example, if students are gathering data that should be represented in a table, consider modeling the setting up of the table and allowing students to practice until they can do this proficiently on their own.

Tip 3: Think aloud.

A “think-aloud” is a way to model thinking to students. Looking for patterns and making meaning of data is a skill that must be practiced and enhanced, and students will need this to be modeled for them. For example, students might create a bar graph that shows the differing amount of daylight hours over a period of time, but they may struggle to interpret that graph. They may benefit from their teacher “thinking aloud” about what this data means. This could look like:

> I notice that the day with the most daylight hours is in the summer, and the day with the shortest daylight hours is in the winter. It looks like the daylight hours in each day between the longest summer day and the shortest winter day gradually decrease. This must mean that each day after the longest day gets a bit shorter until it reaches the shortest day, then each day after that gets a bit longer until we get back to the longest day.

A think-aloud is an effective way of teaching students how to think when interpreting data, but they should not be used in every investigation to give away the big idea. They should be used sparingly, and usually when the data being interpreted is more complicated than previously seen.

Science and Engineering Practice 5—Using Mathematics and Computational Thinking

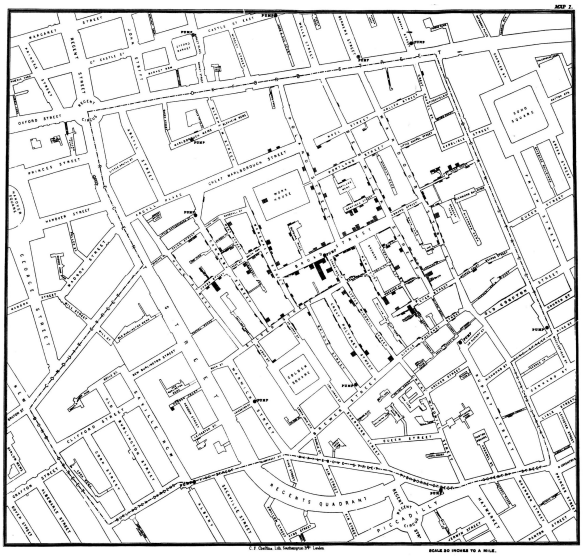
What Is SEP-5—Using Mathematics and Computational Thinking?

Scientists make sense of phenomena that they observe by designing and carrying out investigations. Engineers develop tests to identify whether they have solved specific design problems successfully. Mathematics and computing are the tools used to process information to reveal the patterns in data from investigations and tests. This could be as simple as a chart of different speed calculations or using a computer model to predict percentage increases in growth of a plant.

Why Is SEP-5—Using Mathematics and Computational Thinking Important?

Using Mathematics

In 1854, the physician John Snow conducted an investigation into the cause of a cholera epidemic in Soho, London. He suspected that cholera was contracted by drinking infected water, rather than the bad air that many thought caused the disease. He collected data on who had caught cholera in the area and which water pumps they used. It was only when the data was processed and displayed that the pattern was clear: the water pump in Broad Street was the cause. He convinced the authorities to remove the handle from the pump, and the outbreak slowed and stopped.



The mathematics used in science and engineering need not be very complicated (even just simple ratios), as long as the patterns it produces are clear.

Using Computational Thinking

Scientists and engineers collect huge amounts of qualitative and quantitative data that must be processed consistently and accurately to reveal patterns. This is very time consuming and some tests are not possible.

Look at the Skywalk in the Grand Canyon. It was designed to resist an earthquake of 8.0 and wind speeds of 100 mph, and, if you wanted to, you could place the equivalent of the

mass of 71 airplanes on it before it would bend. You cannot build this structure and test it afterwards. The cost would be too high. So what can you do?



The same is true of traffic flow in South Carolina. Suppose you want to design a new road system to stop congestion. Can you imagine designing a new traffic system without any idea whether it would work or not? The risk would be too great. This is where computational thinking and mathematical modeling comes in.

These days, data about the properties of materials, the strength of structures, or traffic flow figures are stored in databases designed for the purpose of testing solutions or finding patterns. Computer models of the Skywalk and the South Carolina traffic flow store information about many different variables and the relationship between them. These can be used to predict the outcomes of tests and investigations without having to do them for real.

We cannot expect students to do this without extensive teaching and extended practice, which starts the moment they walk into your classroom.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Mathematical and computational thinking in K–2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world(s).

- *Decide when to use qualitative vs. quantitative data.*
- *Use counting and numbers to identify and describe patterns in the natural and designed world(s).*
- *Describe, measure, and/or compare quantitative attributes of different objects and display the data using simple graphs.*
- *Use quantitative data to compare two alternative solutions to a problem.*

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 1, Lesson 4
Students feel the ground outside in different places to identify whether it is hot, cold, or inbetween. They use a thermometer symbol to mark the ground with their measurements, and the teacher collates the responses on a map. Students are therefore exposed to simple

measurement, qualitative data collection, and some simple processing to make the patterns easier to see.

Grade 1
Daylight Data Study
Throughout the year, students investigate patterns of daylight by tracking the Sun at home and sharing their observations at school. They use the Daylight Data handout to record what the Sun is doing when they first wake up, at breakfast, at lunch, at dinner, and at bedtime. To do this, they color the circle yellow if it is daytime, gray if the Sun is just rising or setting, and black if it is night. In Module 4, Patterns in the Sky, students use their data to look for patterns in the natural world.

Grades 3–5

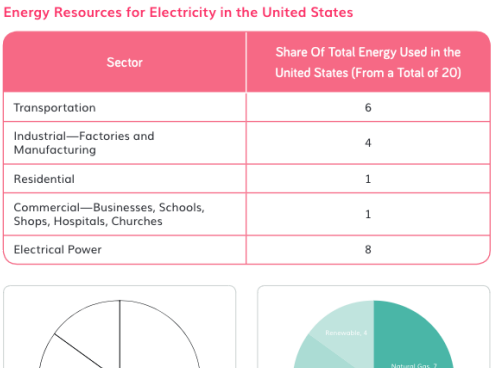
Mathematical and computational thinking in 3–5 builds on K–2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions.

- *Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success.*
- *Organize simple data sets to reveal patterns that suggest relationships.*
- *Describe, measure, estimate, and/or graph quantities (e.g., area, volume, weight, time) to address science and engineering questions and problems.*
- *Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.*

—SCCCR Science Standards Framework

Grade 3
Module 2: Welcome to the Biodome
Driving Question 3, Lesson 6
Prior to this lesson, students have been working with plants in order to determine their traits. In this lesson, students measure the height of plants in a container and then count and measure the seedpods. They record the information in tables and compare the data of their plants in order to find the range and see the variation.

Grade 4
Module 2: Sparks Energy, Inc.
Driving Question 3, Lesson 1
Students use data tables to create pie charts about energy consumption. They compare their pie charts to the tables to understand the advantages of putting data in pictorial form.


Energy Resources for Electricity in the United States

Sector	Share Of Total Energy Used in the United States (From a Total of 20)
Transportation	6
Industrial—Factories and Manufacturing	4
Residential	1
Commercial—Businesses, Schools, Shops, Hospitals, Churches	1
Electrical Power	8

Grade 4
Module 4: Earthquake Engineering
Driving Question 6, Lessons 2 and 3
In Lesson 2, students finish building their earthquake-proof structures and record the height and number of stories of their structures. In Lesson 3, they test their structures and record how long each building survives in an earthquake simulator before collapsing. The teacher determines which team built the most stable structure and spent the least amount of their budget.

Grade 5
Module 1: Matter Mysteries Hotline
Driving Question 3, Lesson 2
Students compare the ingredients of banana bread before and after cooking to see if the mass of the ingredients and products change. This is a two-stage process of calculating the change in mass and producing a double bar graph for each team's data. One bar will be "before data," and one bar will be "after data." Students use the data to answer a specific scientific question.

Grade 5
Module 4: Galactic Guidebook
Driving Question 1, Lesson 3
Students use the Sunrise Sunset Calculator interactive to collect data about varying hours of daylight. The interactive contains a computer model that calculates sunrise and sunset times for each day in a three-year period. It means that students can produce a dataset during a single lesson rather than over many months.

Students analyze the data, organize it within a table, and create bar graphs for one of the three years. The teacher gathers student graphs and organizes them into sets, with each set having one graph for each of the three years. Students review and compare the three graphs.

Top Tips

Tip 1: Make the math accessible.

Remember that the purpose of mathematics in the context of SCCCR Science Standards is to help interpret evidence and not a means in itself. The academic rigor in these lessons should be within the construction of explanations, the analysis of data, and the creation of arguments from evidence. Be aware that students trying to interpret a set of results may struggle to cope with multi-step calculations on top of the interpretation. Reduce the cognitive demand of mathematics in science classes: use straightforward mathematics when processing scientific data, and offer assistance with formulae or spreadsheets if

students struggle to carry out calculations.

Tip 2: Use mathematical thinking to answer questions.

Students may not always understand the reason behind processing data they have collected. Be clear about the purpose of a graph or a calculation before the students do it and how it relates to the problem or question. You might ask prompting questions, such as "What are you hoping to show or prove?" and "Is there a mathematical process that can help us find a pattern in this data?" Students who can articulate answers to these questions are likely to be able to use their processed data to prove their claims.

Tip 3: Model how to interpret graphs.

Link literacy to graphs. Have students sketch graphs relating to elements of the text (for example, in Grade 2, how frightened are the three little pigs at various points during the story?). This will help them understand how lines on a graph reflect the rate of change and that processing in this way makes a pattern clearer. Don't forget to include clear titles and indicate which variable goes on which axis.

Tip 4: Plan out computational thinking.

Provide mini whiteboards so each student can note the ordered steps needed to solve an engineering problem before they start. It is easy for you to check the steps before students begin solving the problem and easy for them to reorder and experiment before they record the process in their Twig Books. This is what an algorithm is: a logical list of steps in the order they need to be completed.

Science and Engineering Practice 6—Constructing Explanations and Designing Solutions

What Is SEP-6—Constructing Explanations and Designing Solutions?

Students' investigations should produce graphs, charts, and graphics that can subsequently be used as evidence to construct explanations, provide answers to scientific questions, or identify best engineering designs.

Why Is SEP-6—Constructing Explanations and Designing Solutions Important?

Science aims to describe the world as it really is, rather than what it appears to be to the individual. To do this, scientists must try to collect data around a specific scientific claim they want to investigate. They then need to construct an explanation based on the current evidence and revise it to account for any new evidence that comes to light over the years. This is the core of what science is about.

For many years, it was claimed that stomach ulcers were caused by stress and lifestyle. In 1982, the scientists Robin Warren and Barry Marshall noticed that a high percentage of people with stomach ulcers had a particular bacterium in their stomachs.They tested more and more people, and found the same bacterium and nearby ulcers. Their new claim was that stomach ulcers were caused by a bacterium and stress had little to do with it. This explanation was not popular with the scientific community, but the evidence was compelling. To prove their point, Dr. Marshall drank some bacteria and gave himself an ulcer. Eventually, the new explanation was accepted due to the strength of the evidence. People with ulcers are now routinely treated with an antibiotic.

In engineering, the task is a little different. The aim is to design objects or processes to solve specific problems and to use tests to decide which of several possible solutions meets the success criteria. A good example is the safety testing of cars. In the past, sand bags, humans (both dead and alive), and animals were all used in tests. In 1949, the first crash-test dummy was produced to model car passengers during a collision. Since then, the dummies have been regularly revised based on extensive testing and knowledge of the forces involved. Later designs of dummy, such as Vince, Larry, and Hybrid III, help engineers accurately model collisions and have helped make cars safer than ever.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.

- *Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena.*
- *Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem.*
- *Generate and/or compare multiple solutions to a problem.*

—SCCCR Science Standards Framework

Kindergarten
Module 2: Marble Run Engineer
Driving Question 3, Lesson 5
Students work in teams to design, build, test, and revise a marble run. They follow specific, common engineering steps and get to know their problem, think of solutions, and decide on a design before building, testing, and revising their design. They also record their findings. Students then reflect on how investigation steps help engineers stay organized and focused during a project so that they can be more creative.

Grade 1
Module 4: Patterns in the Sky
Driving Question 2, Lesson 5
Students have spent the previous few lessons collecting and analyzing data on the Sun. They now write reports about how the amount of daylight changes over the year. They add more detail to the posters they began creating in Driving Question 1 and present their reports to their classmates.

Grade 2
Module 3: Save the Island
Driving Question 1, Lesson 4
Students compare the two volcanic eruption events that they studied in the previous two lessons and organize their thoughts in graphic organizers. Using the evidence they have gathered through videos and texts in previous lessons, they help to compile a class graphic organizer for each of the events. Students then use these graphic organizers to gain evidence to help answer the Driving Question.

Grades 3–5

Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.

- *Construct an explanation of observed relationships (e.g., the distribution of plants in the backyard).*
- *Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.*
- *Identify the evidence that supports particular points in an explanation.*
- *Apply scientific ideas to solve design problems.*
- *Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.*

—SCCCR Science Standards Framework

Grade 3
Module 2: Welcome to the Biodome
Driving Question 3, Lessons 4 and 5
In Lesson 4, student teams use their previous observations to create charts showing how differences in skin colors and patterns help some leaf-tailed geckos escape being eaten by owls. They use their charts in Lesson 5 to write explanations of the survival advantages of camouflage coloration.

Grade 4
Module 2: Sparks Energy, Inc.
Driving Question 2, Lesson 8
Having successfully built and improved their wind turbines in previous lessons, students now consider the effect that wind speed itself has on their turbines. Students incorporate the maximizing of wind speed into the operation of their turbines and attempt the final challenge: lighting a mini light bulb. They then explore a second solution, using the energy of multiple wind turbines to better accomplish the challenge.

Grade 5
Module 4: Galactic Guidebook
Driving Question 3, Lesson 6
Students generate a claim to write a scientific explanation describing why we only see stars at night. They synthesize data and observations from prior investigations to use as evidence to support their claims. Students share their scientific explanations, receive feedback, and make revisions to their writing.

Top Tips

Tip 1: Be prepared.

To help your students construct meaningful explanations from the data they have either produced or been given, make sure you have a firm understanding of the subject knowledge related to the lesson. Read the subject knowledge professional development that comes with Twig Science South Carolina, and review the professional learning films and the questions in the Teacher Edition before the session starts. You may wish to decide upon five key questions to ask to help students construct their own explanations.

Tip 2: Focus minds.

Students struggling to come up with explanations may choose incorrect vocabulary and grammar or drop into slang to get their point across. At that specific moment, when the learning is not secure, it is better to focus on the quality of the scientific explanation or engineering solution rather than use it as a learning point for English Language Arts. Let them have their moment. Once the ideas have been verbalized, use the Stronger and Clearer Each Time language routine with the whole class to improve them, or model it yourself.

Tip 3: Have regular "holler for help" sessions.

Imagine you are two-thirds of the way through a module and students are about to attempt to design a product or construct an explanation. There is likely to be a sizable minority of students who have not grasped the "threshold concept" for this task. This is a crucial idea that must be understood before students can cope with a more complicated task. It can be the one simple thing that is holding a student back.

Stop the class for 10 minutes, and ask everyone to write down any questions they have about their current task and hand them to you. These could include simple things they feel they should understand by now and are therefore embarrassed to ask out loud.

If a student does not know what a compass does, what the word "landform" means, or how to paraphrase text, they will not cope with the task they have been asked to do. Impress on them that sometimes a simple misconception can hold them back and that there is no shame in asking questions. Treat each question seriously as you talk it through with the whole class. It can improve students' general understanding of the module and the outcomes you expect at the end.

Science and Engineering Practice 7—Engaging in Argument from Evidence

What Is SEP-7—Engaging in Argument from Evidence?

Argumentation allows scientists and engineers to present their ideas (either scientific explanations or design solutions), provide evidence and reasoning, and come to a consensus. In science, scientists argue for an explanation about a phenomenon that seems best supported by the evidence; in engineering, engineers argue to identify design solutions that best meet the criteria.

Why Is SEP-7—Engaging in Argument from Evidence Important?

If we want our students to become leaders in science, technology, and engineering in the future, we must equip them with basic literacy in those fields. A key component of scientific and engineering literacy is argumentation—the making of a claim (usually in response to a question) supported with evidence and reasoning.

Argumentation is key to advancements in science and engineering. It allows scientists to present a claim and an explanation for a newly observed phenomenon or to introduce a new explanation for a familiar one. It allows scientists to come to a consensus on explanations for phenomena. In addition, it is the process by which engineers make the case for how well their designs meet criteria.

Throughout their experience with the SCCCR Science Standards Framework, and throughout college if they continue to study science or engineering, students will be asked to argue for or against claims about phenomena or to make claims about designs. They will develop written or oral arguments, including claims, evidence from investigations (in science) or from tests (in engineering), and reasoning connecting evidence to claims. Often, they will be pressed to defend their arguments and to critique the arguments of others.



For students who pursue careers in science or engineering, facility with argumentation will be of utmost importance. As scientists, they will engage in discourse with the rest of the scientific community and will be required to support their emerging explanations about phenomena with evidence as they defend their arguments to peers. Not only does the ability to construct sound arguments gain scientists credibility in the field, it also allows them to contribute to a general scientific understanding of the world that can deeply affect society. For example, think about the impact of the arguments of Copernicus and Galileo that the Sun is

the center of the solar system. Without this argument and its associated evidence, we might still think that the Earth was the center of the universe! For students who pursue engineering as a career, argumentation will be key to their success as they design new solutions for clients. In some cases, they will have to argue that their designs are the best among many. Or they may need to argue that a particular iteration of a design best meets the criteria so that they can wrap up a project.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Engaging in argument from evidence in K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed world(s).

- *Identify arguments that are supported by evidence.*
- *Distinguish between explanations that account for all gathered evidence and those that do not.*
- *Analyze why some evidence is relevant to a scientific question and some is not.*
- *Distinguish between opinions and evidence in one's own explanations.*
- *Listen actively to arguments to indicate agreement or disagreement based on evidence, and/or to retell the main points of the argument.*
- *Construct an argument with evidence to support a claim.*
- *Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence.*

—SCCCR Science Standards Framework

Grade K
Module 4: I Can
Driving Question 1, Lesson 9
Students hear the claims of two fictional scientists ("beavers hurt their environment" and "beavers help their environment") and decide which they agree with based on evidence. Working in pairs, they craft oral scientific arguments arguing for one or other of the claims. With guidance from the teacher, students incorporate evidence from a video and a reading to support their claims.

Grade 2
Module 2: Master of Materials
Driving Question 4, Lesson 7
Students are presented with a fictional problem that they need to help solve: a fruit-juice ice-pop company has discovered that a shipment of ice pops has changed properties. The ice pops are now a warm liquid instead of cold and solid. Students write reports to the ice-pop company including their ideas about what happened, based on their recent investigations, as well as claims about whether or not the change to the ice pops is

reversible. Students support their claims with evidence from previous investigations, creating scientific arguments.

Grades 3–5

Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).

- *Compare and refine arguments based on an evaluation of the evidence presented.*
- *Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation.*
- *Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing specific questions.*
- *Construct and/or support an argument with evidence, data, and/or a model.*
- *Use data to evaluate claims about cause and effect.*
- *Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.*

—SCCCR Science Standards Framework

Grade 3
Module 2: Welcome to the Biodome
Driving Question 4, Lesson 4
Students reflect on what they have observed about the group behavior of different animals and think about the possible benefits of forming groups. Then, working in teams, they generate claims about why birds form groups. They observe a video and look for evidence to support their claims, then re-evaluate their claims based on evidence. Students complete a Claim-Evidence-Reasoning chart and construct scientific arguments about why birds form groups.

Grade 4
Module 2: Sparks Energy, Inc.
Driving Question 3, Lesson 6
Students participate in a debate about the topic decided in the previous lesson, likely to be about the relative merits of different type of energy generation. To prepare for the debate, students review their evidence from earlier module lessons and their Evaluation of Energy Resources chart for information relevant to the debate topic. Students participate in a debate arguing both sides of the given topic using the evidence they have found. Finally, students write brief summaries of the discussion.

Grade 5
Module 4: Galactic Guidebook
Driving Question 2, Lesson 4
Students are presented with two claims in response to the scientific question “Why does the Sun appear brighter than other stars?” Students reflect on the evidence they have gathered, and choose a claim to support (either “The Sun seems brighter than other stars because it is the closest star to Earth” or “The Sun seems brighter than other stars because it is brighter

than all of the other stars"). Students develop scientific arguments as they support their chosen claims with evidence that they have gathered through informational text and investigating a variety of models, as well as reasoning. These arguments serve the dual purpose of giving students experience with the practice of argument-writing and offering an opportunity to check whether students hold a common misconception (that the Sun is brighter than all of the other stars).

Top Tips

Tip 1: Emphasize the difference between scientific and non-scientific arguments.

Students may need reminders that the kinds of arguments they make in science class are different from an argument with a sibling, for example. Explain to students that arguing based on evidence is not the same as fighting to make your point heard or believed. Scientific arguments generally include evidence from data, informational text, or observation, whereas non-scientific arguments are often based on gut feeling or emotion. In scientific argumentation, the idea is to convince another person of one's ideas so that scientists may work together to advance scientific ideas. In non-scientific arguments, there are a variety of different goals.

Tip 2: Encourage student discourse.

Just as the scientific community engages in argumentation as they work to agree upon explanations for phenomena, so can your students. Students should be sharing their scientific arguments with peers, giving and receiving constructive feedback, and working together to strengthen arguments. Students should be asking one another to share evidence and reasoning to support their claims and asking critical questions that prompt self-evaluation. You might consider pulling the class together to evaluate student arguments, asking students "How might you add to this argument? How might you revise it? What evidence do you have to support your claim?" Or you might designate student pairs and use a routine such as Stronger and Clearer Each Time to allow peers to evaluate and work together to strengthen one another's arguments.

Tip 3: Look for connections to math.

Argumentation also appears in the Common Core Mathematics Eight Mathematical Practices. Practice 3 is: Construct viable arguments and critique the reasoning of others. As your students engage in mathematical or scientific argumentation, you might consider looking for any possible connections



between the two. You could have students compare and contrast the two different forms of arguments. Point out to students that the reason this idea is represented in two places is because of its importance.

Science and Engineering Practice 8—Obtaining, Evaluating, and Communicating Information

What Is SEP-8—Obtaining, Evaluating, and Communicating Information?

Any curriculum designed for the 21st century needs to develop students' ability to find, analyze, and critique information. They need to produce written work that persuades as well as uses the correct technical language. At higher grades, comparing information from different sources including textbooks and the media to justify a claim is just as vital. As such, every science or engineering lesson is in part an English Language Arts lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering (NRC Framework, 2012, p. 76).

Why Is SEP-8—Obtaining, Evaluating, and Communicating Information Important?

Being a critical consumer of information about science and engineering (or anything) requires the ability to read or view reports of scientific or technological advances or applications (whether found in the press, online, or in a town meeting) and to recognize salient ideas, identify errors and methodological flaws, and distinguish observations from inferences, arguments from explanations, and claims from evidence. For example, parents wondering whether to vaccinate their child against measles, mumps, and rubella might be concerned about the link between MMR and autism. There are hundreds of studies based on good science and many more that are not. Parents are faced with deciphering multiple sources, including statistics, tables, and graphs, to come to a measured conclusion about what to do. It is vital decisions are based on quality evidence. SEP-8 is therefore a vital practice for all students, whether they go on to study STEM subjects or not.

Progression

The SCCCR Science Standards Framework explains how this SEP should operate at each grade band.

Grades K–2

Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information.

- *Read grade-appropriate texts and/or use media to obtain scientific and/or technical information to determine patterns in and/or evidence about the natural and designed world(s).*

- *Describe how specific images (e.g., a diagram showing how a machine works) support a scientific or engineering idea.*
- *Obtain information using various texts, text features (e.g., headings, tables of contents, glossaries, electronic menus, icons), and other media that will be useful in answering a scientific question and/or supporting a scientific claim.*
- *Communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers that provide detail about scientific ideas, practices, and/or design ideas.*

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 1, Lesson 10
Students have been learning about how to prepare for the weather, learning about different umbrellas and their uses. In this lesson, students listen to the "Under My Umbrella" text. They identify the main topic of the text and find evidence to support their thinking about different types of umbrella and what they are used for.

Grade 1
Module 4: Patterns in the Sky
Driving Question 3, Lesson 7
The teacher reads the title, "The Earth, Moon, Sun, and Stars," with students and reminds them that when they read informational texts they need to think about everything they already know about the topic and prepare to learn something new. Students take a moment to think about what they know and preview the text on their own before beginning to read. As a result of reading the text, pairs of students discuss and record in their graphic organizers what things they think are the same and different between the Earth, Moon, Sun, and stars.

Grade 2
Module 1: My Journey West
Driving Question 3, Lesson 3
Students read two pieces of writing about the ocean: an article and a diary entry. As they read, they consider whether each piece of writing contains scientific information or opinions. In doing so, they elaborate on their learning about oceans and where water is found on Earth.

Grades 3–5

Obtaining, evaluating, and communicating information in 3–5 builds on K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods.

- *Read and comprehend grade- appropriate complex texts and/or other reliable media*

- *to summarize and obtain scientific and technical ideas and describe how they are supported by evidence.*
- *Compare and/or combine across complex texts and/or other reliable media to support the engagement in other science and/or engineering practices.*
- *Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support the engagement in other science and/or engineering practices.*
- *Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem.*
- *Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.*

—SCCCR Science Standards Framework

Grade 4
Module 2: Sparks Energy, Inc.
Driving Question 1, Lesson 3
After learning about some practical uses of transferring energy of motion between objects, students now focus on using transfers of energy from the Sun. They read text and use a comprehension strategy (paraphrasing) to recall content and prepare for writing their Sparks Energy, Inc. website articles in later lessons. They study how to support a main point with reasons and evidence from a text and complete a double-entry journal to engage with the text. Finally, they respond to key words and phrases to check for understanding.

Grade 5
Module 2: Yellowstone—Uncovered
Driving Question 4, Lesson 2
Students read an informational text that describes how energy moves through an ocean ecosystem. Students complete a graphic organizer as they annotate the text to explain the relationships between Antarctic organisms. Students explain the cause-and-effect relationships between individual organisms and the food chain itself.

Top Tips

Tip 1: Choose high-interest text that promotes conversations.

Activities should focus on conceptual change by having students experiment, probe, inquire, question, and examine their thinking. There is a lot of evidence to show that scientific information that credibly links to students' real lives or potential future careers can sometimes be more motivating than abstract academic content. Parents may also help you contextualize content by supplying pictures and marketing material from their places of work.

Tip 2: Develop a supportive classroom climate for learning.

Establish a supportive classroom climate with norms that respect sharing of "first-draft thinking." It is easy to misunderstand nonfiction text, and students need to feel safe and comfortable in the classroom when they struggle with technical vocabulary or misunderstand the meaning of a diagram. A supportive culture in the classroom will help students grapple with challenging ideas in the information they are reading.

Tip 3: Check for understanding through questioning.

Provide students with time to think after a question (including "wait time," writing answers individually, or sharing with partners). Explicitly state that classroom science talk mirrors the practice of professional scientists, and frequently remind students that arguing from evidence with peers is part of "doing science." Try restating student answers to validate and clarify their thoughts. You may want to say, "Let me see if I've got your thinking right. You're saying..." If students are working with partners or in teams, you may want to have them practice active listening and reflection by asking them to restate someone else's reasoning by putting it into their own words.

Tip 4: Use video to establish a context for text.

It can be helpful to show a video about a subject that relates strongly to a piece of nonfiction text students are about to read. It lowers the cognitive demand and helps with familiarity of the vocabulary before students start reading. It can be used as a preamble to guided reading sessions or talk for writing sessions.

Crosscutting Concept 1—Patterns

What Is CCC-1—Patterns?

CCC-1 encourages students to look for patterns in the world around them, particularly as they make observations or review and analyze data. Looking for predictable patterns allows students to begin to formulate answers to the scientific questions they are investigating or develop ideas about the engineering designs they are testing.

Why Is CCC-1—Patterns Important?

Looking for patterns is critical to making sense of data in science and engineering. Identifying patterns in data helps scientists to answer the questions that they set out to investigate and to make predictions about future events. Anomalies revealed by observing patterns may help a scientist to identify an area where further investigation and more data are needed before a phenomenon can be understood. In engineering, noticing patterns during the testing phase of the design process can help an engineer to identify and address areas of weakness in a design.

Teaching students to look for patterns in early elementary years prepares them to analyze and interpret raw data, graphs, charts, and maps, not only as they engage in scientific investigation but in other disciplines and areas of life as well. In elementary and middle school, they gain the ability to analyze data and identify patterns, which prepares them for handling increasingly complex datasets in high school and college. Without these skills, students would struggle to answer questions about the phenomenon under investigation: the data would appear random, lacking in meaning or significance, and be difficult to interpret. Using patterns as a lens through which to analyze and interpret data can help students as they work through mathematical problems, both in and outside the context of science. Patterns can even help students make sense of historical or anthropological data.



The ability to identify patterns in data is key to success in any science-related career that seeks to answer investigable questions and make sense of phenomena, but it can also be a critical skill in careers outside of those in science and engineering. For example, patterns in assessment data can help educators to identify correlations between achievement and

other factors; evaluating patterns in ingredient amounts, cooking times, and ultimate recipe outcomes can allow a chef to make the necessary tweaks to perfect a recipe.

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students recognize that patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 3, Lesson 2
Students look for patterns in temperature data collected during the previous week. They ask questions such as "When is it usually hot?" and "How does the temperature change?" to help them identify patterns. Working in successive pairs, students share the patterns they notice. At the end of the lesson, the teacher asks students to use the patterns that they observed in order to make predictions about whether it will be warmer during the morning or afternoon on the following day.

Grade 1
Module 4: Patterns in the Sky
Driving Question 1, Lesson 4
In order to investigate where the Sun is in the sky at different times, students gather data on the direction of shadows over the course of three days and look for patterns in the shadow data. Students review the data, make observations, and then apply those patterns to make predictions about where the shadow will be at the same time the following day.

Grade 2
Module 1: My Journey West
Driving Question 2, Lesson 3
Students use the River Patterns interactive to explore a map of a portion of the Colorado River and surrounding areas. The teacher introduces the concept of patterns and models looking for patterns using the interactive. Working in pairs, students use the interactive to make observations and record patterns that they notice in the various waterways present. During a class discussion, students share some of the patterns that they noticed in the map, such as: "The water is found in rivers and lakes," "Rivers flow down from mountains/high points," and "In this area, all of the lakes are pretty small and far away from each other."

Grades 3–5

Students identify similarities and differences in order to sort and classify natural objects and designed products. They identify patterns related to time, including simple rates of change and cycles, and to use these patterns to make predictions.

—SCCCR Science Standards Framework

Grade 3
Module 2: Welcome to the Biodome
Driving Question 1, Lesson 2
Students receive a set of cards with images of the eggs of different organisms, such as insects, fish, birds, and amphibians. Students look for patterns across the images, create categories based on those patterns, and sort the cards. Students then reflect on observable patterns between eggs of the same kinds of animals (e.g., amphibians) and develop questions to find out more about the patterns they observe, such as "Why do amphibian eggs have jelly around them?" and "Why do land animals tend to produce eggs with hard shells?"

Grade 4
Module 4: Earthquake Engineering
Driving Question 2, Lesson 4
Throughout this Driving Question, students look for patterns in data to help them predict where earthquakes and volcanic eruptions are likely to occur. In this lesson, students read an informational text about earthquakes, extract data about these events from the text, and record their findings in a table. Students review their tables and look for patterns in earthquake magnitude and amount of damage caused.

Grade 5
Module 4: Galactic Guidebook
Driving Question 5, Lesson 5
Students graph and analyze data they have gathered throughout the module on the length and direction of shadows in the schoolyard. They analyze their graphs to identify patterns in the length of shadows over the course of one day and from day to day. They use the shadow direction data they have collected to identify patterns in shadow direction over the course of one day and identify whether the same patterns appear on different days. Students are then prompted to connect these patterns with a phenomenon that they have observed: that the Earth spins on its axis and completes a full revolution in 24 hours. Synthesizing the patterns with their observations, students identify Earth's eastward spin as the cause of the daily patterns in shadow length and direction that they have identified.

Top Tips

Tip 1: Model grade-specific ways to look for patterns.

Introduce the concept of patterns early in the year, and let students know that they should look for patterns whenever possible in class. Use a think-aloud to model how you expect students to identify patterns at their particular grade level. For example, in Kindergarten, you might show a few pictures of different plants and animals and then model looking for similarities between them. (Ask "What is the same about these two things? What is different?") In Grade 5, students will be well acquainted with the concept of patterns, but they will be graphing complex data to identify causes for an observed effect. You may wish to use a think-aloud strategy as you model looking for patterns to help you identify cause-and-effect relationships in the data.

Tip 2: Encourage students to look for patterns wherever possible.

CCC 1—Patterns is closely tied to the Science and Engineering Practices Analyzing and Interpreting Data (SEP-4) and Using Mathematics and Computational Thinking (SEP-5). Wherever students engage in these SEPs, encourage them to look for patterns that will help them to draw conclusions from or summarize their data. In addition, encourage students to look for patterns in other disciplines. Students might find patterns in art or music classes (visual or musical patterns), in math lessons (multiplication tables), or in Language Arts (a repeating pattern in a story, patterns in how reference books are organized, etc.).



Tip 3: Encourage students to identify non-patterns.

It is equally important for students to understand that some things do not fit into patterns. Early on in the school year, as students analyze data to look for patterns, you may wish to draw their attention to a data set that does not include a clear pattern. You could also identify an incorrect pattern and ask students to review the data and correct you using the Critique, Correct, and Clarify language routine.

Tip 4: Use patterns to engage students.

We want students to identify patterns so that they can make accurate predictions. This is often the end goal of finding patterns, and it can be used to add meaning and excitement to lessons. Many lessons that involve students looking for patterns also require them to make predictions. Capitalize on the predictive aspect to engage students. Students will be excited

about their ability to predict where a shadow might be at a certain time, or where an earthquake might occur, or what the weather might be like in a certain place. This application of knowledge will help students see the value of finding patterns, as well as engaging them in the lesson.

Crosscutting Concept 2—Cause and Effect

What Is CCC-2—Cause and Effect?

Questions about cause-and-effect relationships are the basis for many scientific investigations. Scientists, or students, observe a phenomenon (an effect) and then conduct investigations in order to gather evidence and identify a plausible cause for the observed effect.

Why Is CCC-2—Cause and Effect Important?

Once scientists, or students, identify patterns in data, the next step is to investigate what causes the observed patterns. Scientists and students conduct investigations in which variables are controlled in order to pinpoint the precise cause for an observed effect or to test hypotheses about cause-and-effect relationships.

Engineers, or students, are tasked with developing designs that produce (cause) a desired effect, according to design criteria. Engineers and students test prototypes in order to identify whether their designs produce the desired effect and meet the criteria.

It is critical that students are able to recognize cause-and-effect relationships in order to understand, and design solutions for, the world around them. The ability to identify cause-and-effect relationships is vitally important outside of science and engineering as well—in fact, it serves us in many facets of life. From a very young age, humans identify cause-and-effect relationships as we gather evidence through observation or experience. These can help us make decisions that keep us safe or bring about other desired results (effects). For example, as a young child, you might identify that touching a hot water kettle causes you to experience pain, which will certainly prevent you from deciding to repeat the experience.

The ability to seek out and identify cause-and-effect relationships is a critical skill that helps people to investigate ideas, solve problems, and make sense of the natural and built world. This is true in K-12, college, and in careers in science and engineering, as well as numerous other fields. For example, a marketing specialist might design a marketing campaign aimed at achieving a desired effect; reviewing sales data after campaign launch could identify cause-and-effect relationships between the campaign and sales. An opthamologist might use patient feedback to determine which prescription has the desired effect of improving the patient's vision. A CEO might institute a new company-wide policy aimed at increasing productivity and later review production numbers to determine whether the policy has had the desired effect.



Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students learn that events have causes that generate observable patterns. They design simple tests to gather evidence to support or refute their own ideas about causes.

—SCCCR Science Standards Framework

Kindergarten
Module 4: I Can
Driving Question 1, Lesson 7
Students observe a video of beavers meeting their needs in their environment. Using the Stronger and Clearer Each Time language routine, students share and refine their observations about how the beavers changed their environment. Students then guide the teacher to draw models showing the environment before and after the beavers made changes to it. Together, they complete a chart in which they identify the cause-and-effect relationships between the beavers' actions and the changes to the environment. For example, "Cause: The beavers cut down trees to build a home," and "Effect: There are fewer trees left in the forest."

Grade 1
Module 3: Shadow Town
Driving Question 3, Lesson 9
Students work to design a solution to the problem they have been investigating: the town of Rjukan does not get enough sunlight. They use a model to test the effects of using different materials to reflect light into the town and share their results (design solutions) with the class. The teacher reviews the various solutions that students propose and discusses the effect that each solution (cause) has on the amount of light in the town.

Grade 2
Module 2: Master of Materials
Driving Question 4, Lesson 6
Students watch videos in order to observe what happens (the effect) when three different, familiar materials are heated or cooled (the cause) until they change state. They predict whether the change is reversible and then observe the materials after cooling/heating in order to check their predictions. The teacher introduces the concept of cause-and-effect and probes students to share ideas about what caused the effects that they observed (the change of state from liquid to solid and vice versa).

Grades 3–5

Students routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.

—SCCCR Science Standards Framework

Grade 3
Module 3: How to Survive an Ice Age
Driving Question 1, Lesson 4
Students visit four stations and observe pictures of four different organisms, each displaying a trait that has been influenced by their environment. Students complete a cause-and-effect graphic organizer and pinpoint a specific environmental cause for each trait. For example, they might identify diet as the cause of the flamingo's trait of having pink feathers (the effect).

Grade 4
Module 3: Time Traveling Tour Guides
Driving Question 1, Lesson 1
Students look for evidence of changes (effects) that might have occurred over time in their schoolyard. They record notes and drawings and discuss what might have caused the changes they observed with their partners. For example, they might reason that weathering is a result of water pouring out of a gutter or that erosion may be the effect of children scuffing their feet below a swing. In the lessons that follow, students investigate the various causes of changes to landscapes over time.

Grade 5
Module 4: Galactic Guidebook
Driving Question 4, Lesson 3
Students write a scientific argument about the cause for an effect that they have observed: whenever an object is dropped, anywhere on Earth, the object falls down toward the Earth. Before writing, students use the Critique, Correct, and Clarify language routine to correct an incorrect model of the effect of Earth's gravitational pull on objects. Then, students choose from two possible claims and provide evidence and reasoning to support an argument in response to the prompt question "Why don't we fall off the Earth?" (or, in the language of the CCC, "What causes the effect that humans don't fall off the Earth?").

Top Tips

Tip 1: Discuss evidence of cause-and-effect relationships.

When you introduce this Crosscutting Concept at the start of the year, be sure to discuss how students will gather and review evidence in order to identify cause-and-effect relationships. Before they analyze data from an investigation, have students reflect on what evidence would indicate a cause for the effect being investigated. Ensure students know what to look for as they review the data they collect. Sometimes the action or event (the cause) is observed and then students must look for the effect; other times the effect has been observed and the cause must be identified. Depending on the investigation, you may even wish to consider taking "before" and "after" photos to document the effects of the cause under study.

Tip 2: Where appropriate, connect to the importance of fair tests.



As students plan and conduct hands-on investigations to determine cause-and-effect relationships, emphasize the importance of conducting fair tests (changing only one variable at a time). You could use the Critique, Correct, and Clarify language routine to discuss a hypothetical investigation in which you change two variables, then ask students to explain why it is not possible to determine which change causes the observed effect. For example, if you wanted to determine whether adding water or vinegar to baking soda causes a chemical reaction that results in fizzing, you would not add water and vinegar to the baking soda simultaneously, as it would not be clear which substance caused the chemical reaction.

Tip 3: Encourage partner discussion.

Students may find it hard to articulate their ideas about cause-and-effect relationships at first. Provide them with opportunities to share their ideas with classmates before sharing with the whole class. Use the Stronger and Clearer Each Time language routine to encourage peers to help one another improve their cause-and-effect statements. Encourage students to probe their partners for evidence to ensure that students are supporting their ideas about cause-and-effect relationships with data. Partner discussions should routinely include the question "What is your evidence for this?"

Tip 4: Graphically map out cause-and-effect relationships.

When cause-and-effect relationships are not immediately clear, creating a visual model, like a flow map, will help students to identify and organize causes and their possible effects.



Crosscutting Concept 3—Scale, Proportion, and Quantity

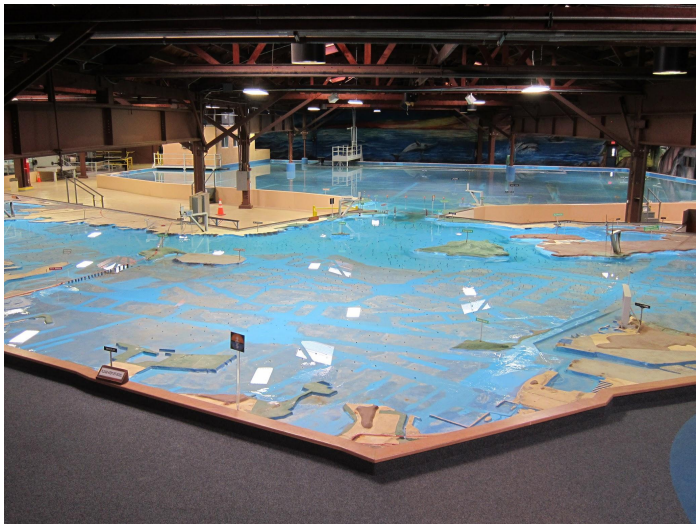
What Is CCC-3—Scale, Proportion, and Quantity?

Scientists investigate questions about the world at many different scales—from that of electrons, for example, to that of a hypergiant star. The concepts of quantity (amounts) and proportion (amounts relative to one another) are key to scientists' and engineers' ability to gather and make sense of empirical data, whether in the context of scientific investigations or engineering design. When investigating scientific phenomena, it is important to consider how changes in scale, proportion, or quantity can affect systems under investigation.

Why Is CCC-3—Scale, Proportion, and Quantity Important?

A solid understanding of the concepts of scale, proportion, and quantity is critical in school, college, careers, and day-to-day life. Students learn about quantity as they begin to count, and they progress to making comparisons based on proportion as they discuss concepts such as "more" and "less." Throughout students' schooling, layers of complexity are added to these concepts. These skills are, of course, critical in mathematics as well. In fact, CCC-3 is tied closely to SEP-5—Using Mathematics and Computational Thinking, and the two are often addressed in tandem.

An understanding of scale, proportion, and quantity plays a key role in numerous, perhaps most, careers in the 21st century. Scale is the foundational concept of maps, landscape drawings, diagrams, and architectural plans, and the ability to interpret scale drawings such as these is critical in many careers and extremely useful outside of work. Understanding the scale on a map, for example, allows a hiker to plan the appropriate length of hike—a map without a scale, or a hiker without an understanding of scale, could result in an unrealistically long or short hike. Scale models allow scientists to study phenomena that may be difficult to observe directly (because of size, accessibility, etc.) and interpret and apply the resulting data. Scale models are incredibly useful to engineers as they design and test solutions or track potential inputs or outputs of systems being designed. For example, in the San Francisco Bay Area, a scale model of the San Francisco Bay was built to test the viability of building two large dams within the Bay and a third on the Sacramento River. The US Army Corps



of Engineers used the model to test these proposals and found that, in fact, they were not viable. Today, the Bay Model provides an opportunity for visitors to comprehend the size of the San Francisco Bay—as long as they understand scale, that is.

Understanding the relationship between proportion and quantity can help a chemist, or a chemistry student, calculate the mass of a substance: if 25 mL of a substance has a mass of 58 g, understanding proportion allows them to calculate that 50 mL of the substance would have a mass of 116 g. In everyday life, understanding the relationship between scale, proportion, and quantity enables you to use a recipe for two servings to make a meal for six people.

Students interested in pursuing careers in technology, science, finance, marketing, social science, architecture and building, pharmacology, forest management, wildlife conservation—the list goes on and on—must have a firm grasp of number sense, scale, and how quantities relate to one another. Understanding scale, proportion, and quantity is vital for carrying out many everyday tasks: food shopping, cooking and baking, managing finances, taking medication, planning events, and so much more.

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students use relative scales (e.g., bigger and smaller; hotter and colder; faster and slower) to describe objects. They use standard units to measure length.

—SCCCR Science Standards Framework

Grade 1
Module 2: Animal Reporters
Driving Question 4, Lesson 1 and Driving Question 5, Lesson 3
In Driving Question 4, students are introduced to the concept that sounds can be loud or soft and connect this to the idea that scientists use a scale to compare sounds. In Driving Question 5, students design communication devices to transmit messages over a long distance. They are reminded that scientists use different scales to measure how loud or soft a sound is. In Lesson 3, they use distance as a scale to determine the loudness of the sounds created by their devices and understand that using distance as a scale helps them to determine which device is the loudest and thus most successful in fulfilling the design criteria.

Grades 3–5

Students recognize natural objects and observable phenomena exist from the very small to the immensely large. They use standard units to measure and describe physical quantities such as weight, time, temperature, and volume.

—SCCCR Science Standards Framework

Grade 3
Module 3: How to Survive an Ice Age
Driving Question 3, Lesson 5
This lesson allows students to explore two different dimensions of CCC-3—Scale, Proportion, and Quantity. The scale of time—in millions of years—frames the lesson. Students reflect on observations they made as they worked with the Ice Age interactive during the previous lesson, then observe a visual introducing them to Petrified Forest National Park in Arizona. Students learn that the fossilized trees in the park are around 225 million years old (predating the Ice Age) and that fossil evidence found in Arizona shows how the area has changed since the Ice Age. Students then compare two maps of Arizona environments—one showing the environments of the Ice Age and the other showing the environments present today. Students record the quantities (in square units) of different types of environments—forest, desert, lakes, grasslands—represented on each map. Having quantified the changes to the region, students are able to draw comparisons and reflect on how the proportion of one type of environment in relation to the others has changed over time. Students conclude that the proportion of land categorized as forest during the Ice Age has greatly decreased. Now the greatest proportion of land is a desert environment.

Grade 5
Module 1: Matter Mysteries Hotline
Driving Question 1, Lesson 2
In the previous lesson, students engaged in an open exploration of the properties of a variety of mystery materials. In this lesson, the teacher records student observations on a chart and asks students to come up with broad categories for the kinds of observations they make (for example, “rough” and “smooth” would fall under the category “texture”). Students are then asked which of the properties on the chart could be investigated by measuring, and identify weight/mass (these concepts are not differentiated in Grade 5) and size. Students share their ideas about which units of measurement are appropriate for measuring weight/mass and size, and the teacher records these as metric units. Students are expected to use these units in their investigations moving forward.

Top Tips

Tip 1: Connect to the CCC whenever possible throughout the year.

Throughout the year, draw connections between student activities as they relate to CCC-3 and prior experiences students have had with scale, proportion, and quantity. Referring back to prior learning can help students make comparisons that further develop their understanding of these concepts. For example, you might compare different objects of study from across the year in order to develop a sense of scale—from the particle level, for instance, to the scale of planets and stars. Similarly, draw connections that allow students to compare proportion and quantity across areas of study.

Tip 2: Reinforce the importance of consistent units of measurement.

It is important that students, particularly those in upper elementary grades, use consistent units of (metric) measurement as they plan and conduct their investigations and analyze the resulting data. Guide students to recognize that the only way to draw clear comparisons and make sound analyses of data is by using consistent units of measurement. If needed, model an example in which you attempt to compare data in, e.g., inches to data collected in centimeters. Have students explain why a valid comparison is not possible and how the problem could be remedied.

Tip 3: Use visuals to help students understand scale, proportion, and quantity.

Some digital interactives can help students to get a sense of scale. Strip diagrams or ratio tables can help students understand proportions. Double number lines can allow students to draw comparisons in quantity. Familiarize students by always discussing the scale and legends on maps, graphs, and charts. You can help students understand the importance of scale (and the effects of changing it) by comparing two graphs or charts of the same data using two different scales.

Crosscutting Concept 4—Systems and System Models

What Is CCC-4—Systems and System Models?

The world is a complex and multifaceted system, composed of both natural and designed elements. Classifying parts of our world into separate systems enables scientists and students to more easily investigate them, often by developing models. Investigation through modeling allows for a better understanding of the structure and function of systems and interactions between systems.

Why Is CCC-4—Systems and System Models Important?

Both naturally occurring and human-made systems can be found everywhere in our world. Humans rely on systems to survive (the circulatory system, the hydrosphere), to communicate (cellular networks), to travel from place to place (transport networks), and to function as a society (the Dewey Decimal system, the court system). When considering the natural, designed, or even the social world, identifying system parts and interactions can help us recognize when a part is not functioning properly and how this affects the function of the system as a whole.

Thinking in terms of systems allows students to begin to explore and understand the world in manageable pieces. Developing models of systems allows students to understand systems that may be difficult to observe directly (such as a cell or the atmosphere) and provides an opportunity for students to communicate their developing ideas.

A system-based perspective is critical in countless career fields and will help students succeed in the future. Understanding the components of industry-specific systems and their functions can help professionals to identify and diagnose problems or to improve systems to generate more desirable outcomes such as productivity, efficiency, employee happiness, etc. For example, an understanding of the mechanical system in a production plant is vital to its operation team—if the system suddenly grinds to a halt or the product being produced is faulty, those operating it should be able to identify and remedy the problem.



A deep familiarity with specific animal body systems is vital to the work of a veterinarian. In-depth knowledge of the various systems that allow a company to function (human resources, finance departments, etc.) allows an Operations Manager to redesign and improve these systems in order to ensure that employee vacation leave is accurately

tracked, clients receive a thank you email each month, and budgets are forecasted with the highest possible level of accuracy.

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students understand objects and organisms can be described in terms of their parts; and systems in the natural and designed world have parts that work together.

—SCCCR Science Standards Framework

Kindergarten
Module 1: My Big Nature Adventure
Driving Question 5, Lesson 8
Throughout this Driving Question, students investigate different habitats and learn that each one is a system: a collection of parts that work together. In this culminating lesson, students apply what they have discovered about different systems (pond, desert, grassland, city) as they draw models that include the parts that make them up (plants, animals, and non-living things).

Grades 3–5

Students understand that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. They can also describe a system in terms of its components and their interactions.

—SCCCR Science Standards Framework

Grade 3
Module 3: How to Survive an Ice Age
Driving Question 4, Lesson 2
In this Driving Question, students investigate how changes to an environment can impact the organisms that live in it. In Lesson 2, they read about the problem of invasive field mustard. Students learn that the invasive mustard plant can prevent the growth of native plants, which in turn removes an important food source for certain native animals. During a reading comprehension discussion, students synthesize the idea that the invasive mustard, which was introduced by humans, is affecting the native plants and animals in the places where it grows. Students are then introduced to the concept of systems in the context of the field mustard scenario. They learn that the function of each part of the environmental system affects the function of the system as a whole. In the following lesson, students design solutions to the field mustard problem in order to protect the system of native plants and animals.

Grade 4
Module 5: Super Survivors
Driving Question 1, Lesson 5
Students investigate body systems through a role-playing activity in which they explore the effect of different modes of respiration on heartbeat. They review a diagram showing the respiratory system and draw connections to their findings about the connection between mode of breathing and heart rate. They use this information, in conjunction with images and videos, to make claims about the parts and function of the respiratory system.

Grade 5
Module 3: H2O Response Team
Driving Question 3, Lesson 2
In prior lessons, students investigate the various parts of three of Earth's systems: the hydrosphere, the atmosphere, and the biosphere. To begin this lesson, students are reminded that scientists often study systems in order to gain information and encouraged to focus on systems as they investigate the Driving Question. Students observe two classroom models demonstrating the system interactions in the process of making rain and forming clouds. As they observe, students draw diagrams of each model and label the parts of each system involved. For example, they might draw raindrops condensing and falling inside the jar representing parts of the hydrosphere system.

Top Tips

Tip 1: Be on the lookout for systems.

Help students notice systems throughout the program and outside of the science classroom. In some cases, a system may be under study even though CCC-4 is not central to the module and so not explicitly mentioned. You may notice that students are reading about, utilizing, modeling, or discussing a system in another discipline in your classroom—perhaps in social studies, math, or language arts. Try to incorporate the concept of systems throughout the day and throughout the school year; when appropriate, stop and ask students to find examples of systems in their learning that day. Remind students that a system is made up of parts that work together and affect one another. You may find that you wish to create a Systems chart on which you record all of the systems that students encounter in all disciplines throughout the school year.



Tip 2: Distinguish between systems and non-systems.

Early on, when you introduce CCC-4, provide an opportunity for students to distinguish between a collection of parts that work together as a system and a collection of parts that are not a system. You might consider using classroom objects, for example. You could introduce a system and discuss its parts (e.g., a computer system that

includes a monitor, cords, and a tower). Have students tell you, in a grade-appropriate manner, how the parts work together: for example, the computer has the information, the cord sends the information to the monitor, the monitor displays the information.

Ask students to consider what might happen if a part were removed (e.g., if the monitor were removed, we would not see the information). Show students a random collection of objects, and ask them to reflect on whether these represent a system. (If you have a classroom lost-and-found pile, that would work well for this purpose, but any set of random objects grouped together will do.) Ask students whether or not the parts of the pile are working together—what would happen if you removed a part? They should recognize that removing an object would not affect the other objects. In this way, demonstrate that not all collections of multiple objects are systems—only those in which the parts work together to perform a function.

During your wrap-up discussion, you might use the following prompts:

- What classifies something as a system?
- Where are systems found?
- Are all systems the same?
- Can all systems be seen?
- Can different systems accomplish the same thing?

Tip 3: Encourage partner discussion.

Particularly at the beginning of the year, when students are either learning a concept for the first time or being reacquainted with it, utilize the Turn and Talk language routine to discuss systems before an all-class discussion. Students may not be comfortable connecting the phenomenon under investigation to the concept of systems, and partner discussion can allow student peers to help one another make such connections in a low-stakes setting.

Crosscutting Concept 5—Energy and Matter

What Is CCC-5—Energy and Matter?

Matter is what things are made of, while energy is what makes things happen. Both are everywhere around us all the time. These principles can help us to understand all manner of scientific systems and processes.

Why Is CCC-5—Energy and Matter Important?

Energy and matter are relevant to every science and engineering discipline. Scientists and engineers track matter and energy through, into, and out of systems in order to understand their functions and capabilities. In the SCCCR Science Standards Framework, CCC-5 often appears in conjunction with systems: for example, students track the transfer of energy through an electrical system or observe the conservation of matter in a chemical reaction. Students will encounter the concepts of energy and matter throughout their academic experiences in science and will be asked time and time again to identify flows of each into or out of systems under study.

The ability to track the flow of matter and energy through systems is critical in numerous careers—it can allow professionals to pinpoint and solve issues and improve the systems on which the rest of us rely. For example, an understanding of the way energy is transferred through an electrical system allows an electrical engineer to design and improve devices that people use daily for work, entertainment, communication, healthcare, manufacturing, and much, much more. Without electrical engineers and their understanding of energy transfer, we wouldn't have the devices that are the basis for modern society such as computers, cell phones, automated manufacturing equipment, life-saving electronic medical equipment, etc. An understanding of how electricity flows is also critical to avoiding electrocution—both for professionals and for the rest of us!



Understanding the flows of matter in an ecosystem can allow ecologists and policymakers to make conservation decisions that are critical to the preservation of endangered or threatened species. If an organism that provides a food source for other organisms is removed from an ecosystem, the organisms that obtain matter (and energy) they need from eating that organism will suffer.

The ability to track the flows of matter and energy through, into, and out of systems will prepare students to problem-solve and succeed in myriad careers. It can also help them know how to safely change light bulbs at home or to identify why their houseplants are drooping!

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students observe that objects may break into smaller pieces, be put together into larger pieces, or change shapes.

—SCCCR Science Standards Framework

Grade 2
Module 2: Master of Materials
Driving Question 5, Lesson 1
Students lay the foundation for the knowledge they will develop in Grade 5: all things are made of matter, which is composed of smaller parts called particles. Students work in pairs to build towers with blocks based on a picture. After their towers are finished, students determine whether it is possible to take them apart and make different towers using the same pieces.

Grades 3–5

Students learn matter is made of particles, and energy can be transferred in various ways and between objects. Students observe the conservation of matter by tracking matter flows and cycles before and after processes and recognizing the total weight of substances does not change.

—SCCCR Science Standards Framework

Grade 4
Module 2: Sparks Energy, Inc.
Driving Question 2, Lesson 6
Students review what they have learned about the transfer of energy from a battery to a motor via the wires of a circuit as they observe a motor spin. They observe that the electric current transforms the stored energy in the battery into electrical energy, which is then transferred as energy of motion by the motor. Next, students build and test a small wind turbine, using a fan to provide the “wind.” Students apply their ideas about the transfer of

energy in a system as they draw and label a diagram of their wind turbine, illustrating the flow of energy. The class discuss their ideas about the source of energy that caused the wind turbine to spin and the transfer of energy that took place.

Grade 5
Module 2: Yellowstone—Uncovered
Driving Question 5, Lesson 3
Having explored relationships between producers and consumers in ecosystems, students model the cycle of matter through an ecosystem. Students use cards depicting different organisms in an ecosystem to show their ideas about the flow of matter: from producers up through higher-level consumers in a food web, until ultimately, all organisms die and their matter is returned to the system (via the soil) by decomposers.

Top Tips

Tip 1: Reinforce the distinction between matter and energy.

In Grades 4 and up, be sure that students are clear on the distinction between matter and energy—in short, matter is what things are made of, while energy is what makes things happen. There are many common misconceptions about the relationship between the two; reinforcing the idea that they are separate but connected can help to dispel these. Note that in Grade 4 students only investigate energy, but you can introduce the idea that energy is not a thing that has mass/weight or takes up space.

Tip 2: Ensure the language used to describe energy is consistent.

A consistent approach across grades can be effective in helping students to grasp concepts of energy. The language should start from the same foundation and build as appropriate according to grade level, with key vocabulary being used consistently throughout. If the vocabulary used is different at each grade level, students may struggle to connect the energy concepts that they are learning from one year to the next. In order to avoid this, you might consider meeting with your K–6 teaching team before the school year begins to iron out the language you will use across grade levels to discuss energy. You can record a glossary and make copies for each teacher. The National Science Teachers Association has a helpful publication about energy that you could use to develop this glossary.

Tip 3: Provide numerous opportunities for students to observe energy transfer.

Direct observation of energy transfers can help students to better grasp this concept. In particular, provide opportunities for students to observe the source of energy, such as wind blowing on a wind turbine that spins to generate a buzzer sound, or a hand-crank generator that lights up an LED. Students can feel the thermal energy emanating from an incandescent bulb (without touching the bulb directly) or observe electrical energy being transferred as light by a torch.



Tip 4: Leverage ELA lessons for introducing the journey of matter into and out of systems.

Use your ELA lessons to produce stories that describe the journey that matter takes in and out of systems. This can help students visualize relationships and interactions that they cannot directly observe. For inspiration, read the chapter on carbon from Primo Levi's book *The Periodic Table*, which has a wonderful description of the journey a carbon atom takes.

Tip 5: Use models to help students visualize the flow of matter and energy.

The flow of matter and energy through a system is often difficult to observe directly. Introduce models such as diagrams and flow charts to help students visualize how matter or energy is transferred through a particular system. Later, students can develop their own models (which can be used as formative assessments) to demonstrate their understanding of the flow of energy or matter.

Crosscutting Concept 6—Structure and Function

What Is CCC-6—Structure and Function?

The structure (or form), of natural and built objects, parts, or systems is correlated to their function (what they do). This principle can give students a deeper understanding of structures and systems in science class and is a critical consideration in engineering design projects.

Why Is CCC-6—Structure and Function Important?

Much scientific discovery is based on investigations of the structures of various natural objects, components, or systems, in order to understand their function as part of a greater system. Such investigations have helped scientists understand the world around us, from a very small scale (such as at the molecular level), to a very large scale (such as at the Earth systems level) and everything in between (including the structures that make up humans and other animals, for example). An understanding of structure and function at each of these levels informs numerous other disciplines and professions. For example, understanding the relationship between our body structures and their functions has been critical to the advancement of medicine and medical devices, and this understanding also informs decisions that doctors make about their patients' health. Understanding the structure and function of the atmosphere is part of what allows meteorologists to predict our weather each day.

An understanding of the structure and function of natural objects, parts, or systems can also inform engineering design. Knowing the structure of a material at the molecular level informs an engineer as to the suitability of that material for a particular function in a design. Biomimicry is a field in which engineers use knowledge of the function of biological structures (for example, the fins of a humpback whale, the beak of a kingfisher, or the shape of a termite mound) as inspiration for design solutions (an efficient wind turbine, a quieter bullet train, and a more sustainable office building, respectively).





Understanding that structures of natural and designed objects and systems have correlated functions will provide students with a basis for understanding the world around them. This

base of knowledge may spark student curiosity and inquiry and provide inspiration for future careers in science or engineering.

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students observe the shape and stability of structures of natural and designed objects are related to their function(s).

—SCCCR Science Standards Framework

Kindergarten
Module 3: Be Prepared
Driving Question 1, Lesson 1
Students watch a video that depicts people using different kinds of umbrellas for different purposes (in different kinds of weather). Students are presented with a table with four different kinds of weather in one column, and four umbrellas with different structures in the other column. The teacher prompts students to pay attention to the structure of each umbrella and to think about the circumstances in which each might be used. Students use their ideas about shape and use (structure and function) to match the umbrellas (a rain umbrella, a beach umbrella, a picnic-table umbrella, and a parasol) to the appropriate use.

Grade 2
Module 4: A Garden for Life
Driving Question 3, Lesson 7
Students refine their ideas about the structures of pollinators and their function in the pollination process as they begin to design models of flowers and pollinators. They reflect on what they have observed about various pollinators and flowers through videos and images and identify which materials would best help them to mimic the structures they are trying to model, based on their texture, appearance, and function in the pollination process. For example, if students are creating a model of a bee, they might choose a hook-and-loop fastener for the legs, as they have observed that bees' legs are fuzzy and function as pollen collectors.

Grades 3–5

Students learn different materials have different substructures, which can sometimes be observed; and substructures have shapes and parts that serve functions.

—SCCCR Science Standards Framework

Grade 4
Module 5: Super Survivors
Driving Question 1, Lesson 7

Students begin by reading about a predator and identify the structures that allow the animal to catch and kill its prey. Next, students design and draw an imaginary prey animal with body structures that serve a specific function: to help it evade its predator. Students then engage in a brief writing activity in which they respond to the prompt "How do the different parts of our prey animal help it escape being eaten?" They use the imaginary structures that protect their imaginary prey as evidence to support their claims, then present their animals and its body structures to the class. Working in successive pairs, students reflect on the day's learning and share their ideas about the question "How do an animal's body structures help it hunt for food or protect itself from predators?"

Top Tips

Tip 1: Prepare students with language to discuss structure and function.

Encourage students to talk to their peers about structure and function as they work. Provide them with phrases they can use to prompt their peers to share ideas and make connections between the shape and form of something under study and its purpose. For example, you could write the following prompts on the board or add to a bulletin board:

- Describe the structure of the object or part.
- Why do you think it is shaped like that?
- What function does this part/object serve?
- How does the structure of this object or part make it suited to its function?

As students investigate, have them refer to these questions and ask their peers for possible answers or record their own answers in their science journals. Develop a classroom culture in which taking an informed guess about the function of a structure is rewarded. Bring the class together after partner discussion or journal-writing, and have students share their ideas.

Tip 2: Connect to patterns.

Throughout their investigations, encourage students to use patterns that they have observed in order to make predictions about the function of structures. For example, after investigating a variety of organisms with fur and discovering that fur keeps animals warm, students could predict that the fur on a newly introduced animal would also serve to keep it warm. However, students, like scientists, cannot assume that the patterns they have observed always apply or that similar structures always serve the same function. The predictions they make should serve as a first step in planning and conducting an investigation to determine the function of a particular structure. If the newly introduced animal were a bumblebee, the function of the hair would be completely different than that of the hair found on mammals. Students would need to investigate further to reveal this different structure/function relationship.

Tip 3: Use visuals and models to help students reflect on the function of structures.

Before they can fully understand the relationship between a structure and its function, or determine the function of a structure, students need to be able to visualize the structure in

3-D. This is particularly true if the structure is too large or small to be directly observed. Videos, digital interactives, diagrams, and physical models can all help students to develop a clear mental image of a structure before they begin investigating its function. Building their own physical models can also help students to develop a clear idea about a structure, as long as the model is focused on the structure being investigated and not the greater system.



Tip 4: Start with visible, tangible structures.

It will be much easier for students to investigate and conceive of structure/function relationships in structures that are visible (e.g., bird beaks, seed coverings) than those that are not (e.g., organelles). Start out with structures that students can easily observe—directly or indirectly—then progress to the microscopic scale once they have a firm grasp of structure/function relationships. There are many opportunities throughout the Twig Science South Carolina program for students to observe representations and/or build models of structures as they investigate or share their ideas about their function.

Tip 5: Scaffold students' exploration of structure/function relationships.

For example, a partially completed graphic organizer listing a number of structures and their functions could activate students' thought process if they are struggling to make structure/function connections.

Tip 6: Understand that sometimes students will identify the structure and other times the function.

Students may need to be made aware that, when analyzing structure and function, sometimes we start by knowing the structure and use that to investigate, or determine, the function. Other times we know the function, but we have to investigate to determine the structure. For example, in the pollination lesson mentioned above, students see the structure of the pollinators and the hair on the bees' legs, and they use this information to speculate on or investigate the function of that hair. Conversely, they may know that the function of a bicycle pedal is to move the bicycle forward but have to investigate to determine how the structure of the pedals actually makes that forward movement possible. Being able to think about structure as it relates to function, and function as it relates to structure, is what allows scientists and engineers to make advances in their fields.

Crosscutting Concept 7—Stability and Change

What Is CCC-7—Stability and Change?

CCC-7—Stability and Change is a lens through which to observe systems or parts of systems. Flows into and out of systems can cause those systems to change in a manner that is cyclical (therefore achieving a stable effect) or in a way that is anomalous (sudden and not befitting a pattern).

Why Is CCC-7—Stability and Change Important?

There is a natural progression from CCC-1—Patterns to CCC-7—Stability and Change. Students first learn how to look for patterns (events that occur with predictability), then to look for anomalies within those patterns. Students must look for the (actual or apparent) stability—the pattern; then, they can notice the change—the anomaly in the pattern. Likewise, in science and engineering, a pattern in the data must first be established before an anomaly, or a change, can be identified.

The concept of stability and change is central to the fields of science and engineering. Climate scientists have studied atmospheric carbon dioxide levels and global temperature and determined that, while there are natural cycles of fluctuation, there has been overall stability. However, data from the mid-20th century onward no longer follows the stable pattern of fluctuation that has been observed from thousands of years' worth of data. Suddenly, global temperatures and carbon dioxide levels dramatically increased in the 20th century, far beyond the highest points of the natural cycles that had previously been observed. This data, along with an understanding of the timeline of human activities that release large quantities of carbon dioxide, is one piece of evidence that climate scientists use to argue that the increased rate of climate change is caused by human activity.



Engineers know that systems are always changing, and they must take this into account when designing structures. Such changes can be gradual (e.g., erosion) or sudden (mudslide, earthquake, or flood). Bridges, particularly in earthquake-prone areas, are designed to withstand sudden changes such as earthquakes. Seawalls are designed to withstand changing tides. A wise developer would be sure to have an engineer design roads and structures that can withstand or even help prevent the inevitable erosion of a seaside cliff.

Without this acknowledgement of the inevitability of change, cliff-top roads and buildings are likely to end up at the cliff's bottom.

Understanding stability and change also helps professionals in other fields to make sense of the patterns they see in data. For example, by understanding the pattern of stability and change in the sales of certain items, a savvy store owner will be able to recognize that they are more likely to sell ice pops in the summer and hot drinks in the winter.

Stability and change is a concept relevant to all processes and systems. A firm grasp of this concept will help students to succeed in 21st century careers and potentially to work to solve some of the problems that this lens has helped others to identify.

Progression

The SCCCR Science Standards Framework explains how this CCC should operate at each grade band.

Grades K–2

Students observe some things stay the same while other things change, and things may change slowly or rapidly.

—SCCCR Science Standards Framework

Grade 1
Module 1: Museum of Leafology
Driving Question 4, Lesson 3
A time lapse video at the beginning of this lesson highlights the idea that plants change over time. Students begin to grasp the important idea that changes can happen rapidly or slowly. In this module, students observe plants growing, and this video shows them that even though the plant may not seem to change on a day to day basis, changes are still occurring.

Grade 2
Module 3: Save the Island
Driving Question 1, Lesson 3
Students listen to a read-aloud about two Japanese islands that were formed by volcanoes and are still changing as the volcanoes continue to erupt. Students must listen carefully to the text for evidence of whether these changes occurred quickly or slowly. After the reading is over, they point out textual evidence that the changes to the islands' landscapes have occurred very slowly. After listening carefully and visualizing while listening, students draw their ideas about the changes to the islands. They compare the rate of change to the volcanic landscape in this article with that of fast-erupting Mount St. Helen's, which they investigated previously. Students then watch a video showing the eruption of Mount Kilauea. They engage in the Stronger and Clearer Each Time language routine to share their

ideas about the impact of Mount Kilauea's eruption on the landscape and the speed at which the changes occurred.

Grades 3–5

Students measure change in terms of differences over time, and observe that change may occur at different rates. Students learn some systems appear stable, but over long periods of time they will eventually change.

—SCCCR Science Standards Framework

Grade 4
Module 3: Time-Traveling Tour Guides
Driving Question 1, Lesson 3





Students read and compare texts describing changes to the Great Wall of China and California missions over time. As they read, they make note of when and how the structures were built and the causes and effects of weathering and erosion throughout the years. During a reading comprehension discussion, students reflect on why the structures began to erode (change) and what sped up the process (rate of change). The teacher points out that although the structures may seem stable and unchanging at present, reading accounts from when they were built allows people to learn about the changes that have taken place slowly over the years.

Top Tips

Tip 1: Notice changes in patterns.

Before students can look for stability and change in systems, they must understand how to look for patterns. Early on in the school year, introduce CCC-1—Patterns and help students adopt the skill of looking for patterns in data. Once students are able to identify patterns and use them to make predictions, they are equipped to look for instances of stability and change.

Tip 2: Remind students that stability doesn't mean lack of change.

A system may undergo constant cyclical change, with the overall effect of stability and predictability. Alternatively, these cyclical changes may occur at a rate that is difficult to observe, and so at the time of investigation a system may appear unchanging. For example,

scientists may not immediately observe the gradual changes taking place as weathering changes a cliff face, so it may appear static and unchanging. However, longitudinal data may reveal that the cliff face has been changing at a slow and steady pace. Noticing the distinction between cyclical changes that cause stability and truly anomalous changes will serve students as they use this Crosscutting Concept.

Tip 3: Use graphs and models to track stability and change.

Depending on the scale of time or of the particular changes under investigation, students may find it challenging to identify instances of stability and change. Developing graphs (when there is quantitative data available) and models (for qualitative and quantitative data) can help students to look for these patterns and anomalies. You may wish to begin by modeling how to develop and use these tools in this way, then release responsibility to students to develop and use their own graphs and models as needed.

Tip 4: Discuss and track time scale.



Change can happen very slowly—so slowly it might be missed and can't be observed over a short period. For example, trees, rock faces, buildings, and lakes look stable and don't seem to change unless you look at them over longer periods of time. To help students observe the kinds of changes that happen slowly over time, you could show a film of time-lapse photography or ask students to measure something over long periods, like day length or the phases of the moon. Creating diagrams showing the observed changes over time and logging the date the data was gathered can help students to visualize the changes taking place.