A SCIENCE EDUCATION CURRICULUM STUDY

Strategies for Effective Science Teaching:
The Student Thinking and Science Content Storyline Lenses
Grade 4

STeLLA Conceptual Framework

STUDENT THINKING

Learning to analyze science teaching through two lenses

SCIENCE CONTENT STORYLINE

allows you to learn and use strategies for more effective science teaching.

SCIENCE TEACHING

STRATEGIES TO REVEAL, SUPPORT, AND CHALLENGE STUDENT THINKING

1. Ask questions to elicit student ideas and predictions.
2. Ask questions to probe student ideas and predictions.
3. Ask questions to challenge student thinking.
4. Engage students in analyzing and interpreting data and observations.
5. Engage students in constructing explanations and arguments.
6. Engage students in using and applying new science ideas in a variety of ways and contexts.
7. Engage students in making connections by synthesizing and summarizing key science ideas.
8. Engage students in communicating in scientific ways.

STRATEGIES TO CREATE A COHERENT SCIENCE CONTENT STORYLINE

A. Identify one main learning goal.

B. Set the purpose with a focus question or goal statement.

C. Select activities that are matched to the learning goal.

D. Select content representations and models matched to the learning goal and engage students in their use.

E. Sequence key science ideas and activities appropriately.

F. Make explicit links between science ideas and activities.

G. Link science ideas to other science ideas.

H. Highlight key science ideas and focus question throughout.

I. Summarize key science ideas.

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Contents

How to Learn from Lesson Analysis: The Basics

In this professional development program, you'll be viewing videos of classroom teaching and interviews with students and teachers, as well as answering questions that are designed to help you deepen your understanding of science and science teaching by guiding you to become more analytical about science lessons. You'll also learn to analyze science teaching by focusing your attention on two key issues: student thinking and the science content storyline. These two ways of looking at science teaching will be discussed later. For now, we need to establish some important ground rules—viewing basics for watching the videos and analysis basics for how to begin analyzing video-recorded science teaching in this program.

Viewing Basics

Viewing Basic 1: Look Past the Trivial, or Little Things, That Bug You

Keep in mind that real teachers and students are recorded in the classroom videos. Because they're human, they might do things you find annoying or frustrating. For example, a teacher might have certain mannerisms that annoy you or a high-pitched voice that irritates you. She may repeat the same phrase over and over ("OK" or "good" or "like"). He might seem too energetic and silly, or too boring and monotone for your taste. But mannerisms and word choice aren't essential features for high-quality science teaching. Learn to look past them.

You should also not expect perfect, television-quality camera work. Classrooms are very difficult places to video record, and the videographers are trying to capture the real thing in real time, not a staged lesson on a controlled set. For these lessons, the priority was to get the best possible sound quality from students and show exactly what they were seeing and doing during the activities. To capture all of this, the videographers had to move quickly from one part of the classroom to another. You'll begin to appreciate this reality style of videography as you work with the videos.

Viewing Basic 2: Avoid the "This Doesn't Look Like My Classroom!" Trap

It's unlikely that the student populations and physical facilities you see in the video clips will exactly match your own classroom. A classroom might be in an inner city or a rural area; the class might be a charter school where students call teachers by their first names, or it might be a school where the science-resource teacher doesn't know all of the students' names. Because of this, it might be tempting to say, "These kids aren't like my students, and my classroom doesn't have these resources, so this lesson doesn't speak to my situation." But every teacher needs to understand the science content, use that knowledge to develop a coherent science storyline in the lessons, and pay attention to students' thinking and learning. These are the essentials of science teaching, and they apply to all students in all kinds of communities.

Viewing Basic 3: Avoid Making Snap Judgments about the Teaching or Learning in the Classroom You're Viewing

As you watch classroom videos, it's easy to make quick judgments about the teacher, the students, and the classroom environment. These judgments can be either positive—"I really like how the teacher conducted that activity"—or negative—"The teacher never uses any wait time; she always rushes the students." Remember you're viewing only a brief snapshot of classroom interactions, so it's dangerous to generalize that "the teacher always does this" or "the students always do that" from a few minutes of video. Also, it's not always helpful to focus on what you like or don't like about what you see and hear. When watching a video, it's best to base your ideas on specific observations and evidence, which you'll learn more about as you examine the STeLLA lenses and strategies.

Analysis Basics

Analysis Basic 1: Focus on Student Thinking and the Science Content Storyline

Your learning will be maximized if you limit your focus to a close scrutiny of student thinking and the development of the science content storyline in the lessons. Set aside for later your interest in other important issues, such as classroom management and gender equity. As you observe interesting moments in a video or find you have a question or judgment, make a note of it. This will become your claim.

Analysis Basic 2: Look for Evidence to Support Any Claims

Another key step in video-based lesson analysis is the identification of specific evidence to support your claims. As you look at video clips of student work, get in the habit of identifying specific time markers and statements the teacher or the students make that support your thinking about an event. Referring to video transcripts is essential in this process.

- **Claim:** It seems like Miriam doesn't really understand the idea that water moves Earth's materials from higher places to lower places, resulting in canyons and valleys.
- **Evidence:** At video segment 16:54, the teacher asks a group of students to explain what's happening in the picture of the rushing stream. Miriam describes how the stream is making the mountain taller by "bringing more rocks and dirt together."

Analysis Basic 3: Look More Than Once

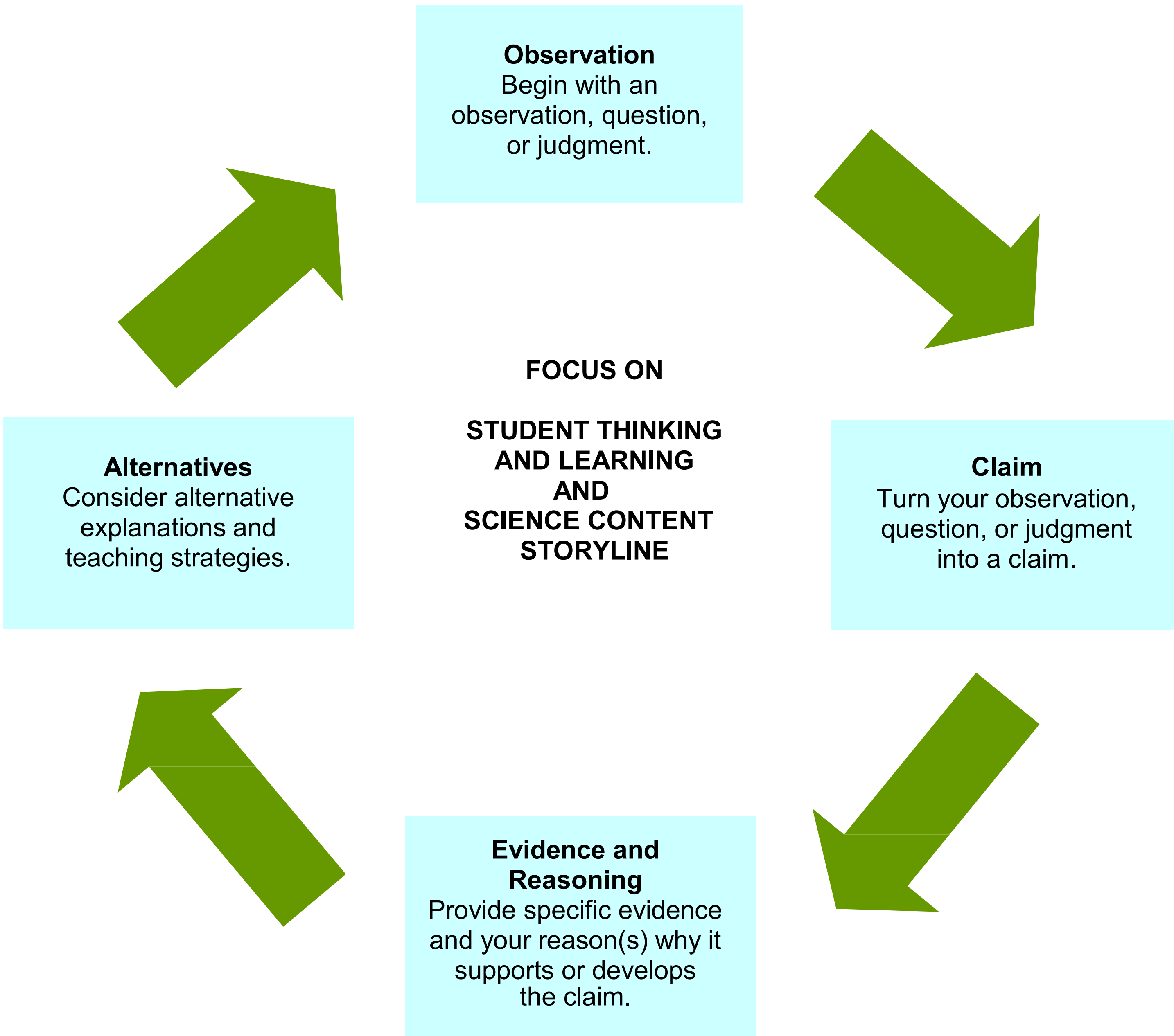
Video recording enables us to look at a teaching episode over and over. Take advantage of this opportunity. To deepen your learning from analyzing classroom videos, look at them more than once. Studying transcripts is a powerful way of revisiting a lesson clip. Let go of your everyday *entertainment view* of video watching ("I've already seen that movie") and adopt an *analysis view*.

Analysis Basic 4: Consider Alternative Explanations and Teaching Strategies

A final key step in video-based lesson analysis is setting aside your first reaction and refining or modifying quick judgments. Turn your reaction or initial judgment into a question and then consider alternative explanations for what you're observing. For example:

- **Initial judgment:** *It bothers me that the teacher never answers students' questions. The students must be frustrated.*
- **Questions:** *Why doesn't she answer students' questions? Does this frustrate them?*
- **Alternative explanation:** *The teacher will answer their questions eventually, but for now she just wants students to see the wide range of ideas they have.*
- **Alternative explanation:** *The teacher wants students to answer their own questions and become more active in taking responsibility for their own learning.*
- **Alternative explanation:** *The students are used to this process, so it doesn't frustrate them. They know the teacher values their questions.*
- **Alternative teaching strategy:** *To show that students' questions are valued, the teacher could record them on a class chart or in a class question notebook.*

Learning from Lesson Analysis



Analysis of Student Thinking

Lesson Analysis Stage	Example
Observation Begin with an observation, question, or judgment.	• Do the students really understand this activity?
Claim Turn your observation, question, or judgment into a specific claim.	• I don't think students understand that this activity is intended to demonstrate both erosion and deposition.
Evidence and Reasoning Provide specific evidence and reason(s) why it supports or develops the claim.	• In the video, when Daniel pours water onto the stream table, he says, "Wow, the sand is going everywhere." Another student in the group says, "We have to use science words to describe what is happening." Daniel says, "Oh. The water is causing the sand to erode." I think he might be grouping erosion and deposition together as one process.
Alternatives Consider alternative explanations and teaching strategies.	• A probe question would clarify whether Daniel is labeling the areas of deposition as erosion, or whether he understands that erosion is the process of moving the soil, and deposition is where the soil is deposited as a result.

Analysis of Science Content Storyline

Lesson Analysis Stage	Example
Observation Begin with an observation, question, or judgment.	• I don't think students are connecting the activity to the learning goal: Energy is conserved when it's transferred from one body to another in a collision.
Claim Turn your observation, question, or judgment into a specific claim.	• The teacher didn't help students make the connection between the activity and the science ideas they were supposed to learn.
Evidence and Reasoning Provide specific evidence and reason(s) why it supports or develops the claim.	• The focus question gets students thinking about where energy is going but doesn't infer that it can't be created or destroyed. The setup to the activity gets kids thinking about what might happen to energy in a collision. At that point, there is no discussion of conservation. One student in the video notes that "Mumford lost energy, and Leroy gained energy." He may think Mumford destroyed energy and Leroy created energy instead of realizing that the energy simply transferred from Mumford to Leroy.
Alternatives Consider alternative explanations or teaching strategies.	• The teacher might have helped students make a connection to the learning goal by asking them to think about how much of Mumford's energy was transferred to Leroy. If they pointed out that Leroy didn't move as fast or as far as Mumford would have if the collision hadn't happened, then they could have explored any evidence of how the energy might have changed to make the amount before and after the collision equal.

Student Ideas and Science Ideas Defined

Student Ideas

Students don't come to science classrooms as blank slates. Based on their experiences, observations, and learning about the world they live in, they bring to the table many ideas about how to explain events (phenomena) in the world around them. Their ideas are often different from the ideas scientists have developed over centuries of research. Because of this, we sometimes refer to student ideas as "common student ideas," "misconceptions," or "naive theories." These descriptions highlight the fact that their ideas often don't match scientific ideas. But this is not to say that students' ideas are wrong and should be ignored, discounted, or replaced. Quite the contrary. If we listen carefully to their ideas, we discover that their thinking makes a lot of sense based on the evidence available to them. We can find important nuggets of scientific truth in their thinking. To help students build on and change their ideas about the world around them, we should look for the logic in their ideas and think about how they developed those ideas. Then we can plan experiences and provide evidence that will challenge them to deepen their thinking or reconsider their ideas. In STeLLA, we use the phrase *student ideas* to acknowledge their importance and value in shaping our planning and teaching of science. However, student ideas are not necessarily the same thing as science ideas.

Science Ideas

In STeLLA, we use the term *science ideas* in a very particular way.

A **science idea** is a complete sentence (or more) describing scientific knowledge that a student can learn. Think of it as a knowledge outcome in a lesson. A science idea is consistent with knowledge that is agreed upon as part of the scientific-knowledge base that is well supported by evidence.

A science idea is **NOT**

- a topic (earthquakes, energy, motion),
- a student activity (("Students are testing the angle of incline in a ramp and the speed of a marble."),
- a set of instructions,
- a question, or
- an interesting student idea that is not scientifically accurate.

In planning and teaching science, it's important to state science ideas in complete sentences to clarify exactly what it is we want students to understand, and how science ideas are different from common student ideas. If we say that our goal is to help students understand energy (a topic), we aren't clarifying the difference between what students think about energy in their world and what scientists have learned about how energy transfers and transforms in interactions between objects.

There are many different kinds of science ideas. Science ideas can be stated as facts, terminology, descriptions of observations, explanations of phenomena, concepts, patterns, laws, principles, or theories the scientific community accepts as established ways to describe natural phenomena (often referred to as *canonical knowledge*). Following are some examples of science ideas that range from simple facts to concepts and theoretical ideas.

Examples of Science Ideas Related to Earth's Changing Surface

a. Pumice is igneous rock. *(Fact)*
b. Mountains in the western US are taller and less rounded than mountains in the eastern US. *(Accurate statement and observable pattern)*
c. Earth's surface is continually being worn away in some places and built up in other places. *(Concept)*
d. Mountains form as a result of the movement of Earth's tectonic plates. *(Scientific theory)*

Examples of Science Ideas Related to Energy Transfer

a. Potential energy is a type of stored energy. *(Fact)*
b. Energy often leaves a system as heat. *(Accurate statement and observable pattern)*
c. When two objects collide, energy is transferred from one object to another. *(Concept)*
d. Energy can move from one object to another but is neither created nor destroyed; it is conserved. *(Scientific theory)*

Strategies to Reveal, Support, and Challenge Student Thinking

Defining the STeLLA Student Thinking Lens

A major role for you as a teacher is to elicit student ideas and guide their thinking. To continuously diagnose and assess your students' understandings and confusion, you need to use teaching strategies that will make your student thinking visible to you. This means encouraging students to communicate about new ideas as much as possible and helping them elaborate on their ideas by speaking and writing in complete sentences or even paragraphs. You can elicit student thinking when you lead whole-class discussions or engage with individual students or small groups as they work on activities independently. Student thinking can also be revealed to you through their writings, drawings, presentations, and hands-on work with science materials.

Once student thinking is made visible, you need to listen and be on the lookout for misunderstandings, misconceptions, or naive theories just as actively as you look for right answers. Go beyond identifying "wrong" answers and focus instead on figuring out how students' ways of thinking and sensemaking are leading them astray. Diagnosing these misunderstandings is the first step toward supporting students in the challenging process of changing their misconceptions and developing more-scientific explanations of the world around them.

Through the Student Thinking Lens, you'll learn the importance of students' ideas and how to reveal, support, and challenge student thinking. STeLLA presents eight specific strategies teachers can use to focus on student thinking:

1. Ask questions to elicit student ideas and predictions.
2. Ask questions to probe student ideas and predictions.
3. Ask questions to challenge student thinking.
4. Engage students in analyzing and interpreting data and observations.
5. Engage students in constructing explanations and arguments.
6. Engage students in using and applying new science ideas in a variety of ways and contexts.
7. Engage students in making connections by synthesizing and summarizing key science ideas.
8. Engage students in communicating in scientific ways.

Each of these strategies supports teachers in revealing, supporting, and challenging students' scientific thinking:

- Strategies 1–3 focus on particular types of *questions* teachers can ask that help students learn to think and reason scientifically and develop understandings of core ideas and crosscutting concepts in science.
- Strategies 4–7 reveal, support, and challenge student thinking by engaging them in four types of *activities* that are especially important in learning science.
- Strategy 8 helps teachers instruct students explicitly about how to think and communicate like scientists. This strategy engages students in learning to use the eight scientific *practices* identified in the *Next Generation Science Standards* (NGSS Lead States, 2013).

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 1:
Ask Questions to Elicit Student Ideas and Predictions

Questions and activities reveal student thinking by eliciting prior knowledge, experiences, and predictions relevant to the learning goal. Before studying how the surface of Earth changes or about energy in their daily lives, what personal theories do students have about how mountains form or what happens to energy when objects collide? What do students think about why the surface of Earth has such variations—high places, low places, flat places, river valleys? What do they predict will happen to the speed of an object when it strikes a stationary object?

A question or activity designed to elicit students' initial ideas and predictions is addressed to multiple students (the whole class or a small group) and results in a variety of student ideas rather than one "right" answer. The goal of these questions and activities is to learn about students' prior knowledge, misconceptions, experiences, and ways of making sense—whether or not their ideas are scientifically accurate. The more you can understand how students think about phenomena and science ideas, the better you can adapt your instruction in future lessons to challenge their misconceptions and support them in changing their ideas toward more-scientific, evidence-based understandings.

Questions that elicit student thinking also play a role in engaging students in the topic of study—helping them see the links between their own ideas and the science ideas they will learn in the lesson. Students are also able to see that different people have different ideas. This sets up a need to find out which ideas are best.

Predictions can often be used effectively to elicit students' initial ideas. You'll want to take note of these ideas, since they can later be challenged by using a "discrepant event." A *discrepant event* is an observation or piece of information that doesn't match student predictions. For example, students may predict that a flashlight must have a battery to work. Observing a hand-crank flashlight is a discrepant event that challenges students to rethink their ideas. You'll learn more about questions that challenge student thinking when you study STeLLA Student Thinking Lens strategy 3.

Questions that elicit student ideas should be phrased in everyday language that will make sense to students even before they begin a unit of study. If a teacher asks, "What do you think potential energy is?" most students will have nothing to contribute. In contrast, many students will be able to respond to a question that asks, "Why does a bike at the top of a hill start to move?" It's best to avoid using scientific terminology when eliciting student ideas. Instead, think of an everyday connection and everyday words that students can explore.

When Is Strategy 1 Used?

- When a new idea is going to be introduced (often at the beginning of a unit or lesson)
- To set up a discrepant event at any point in the unit of study

Response to Student Ideas

- Make it clear that you aren't going to tell students which ideas are right or wrong at this point. Confusion may result if students are unclear about which of their peers' ideas are "right" from a scientific perspective, and which are just interesting, so make sure to give your reasons for taking this approach. For example, you might say,

    - “Right now we’re just getting our ideas out there. These are just our predictions about ______. Later, we’ll gather some evidence to see if we can support or challenge any of our predictions.”
    - “As you listen to different ideas, think about which ideas you agree or disagree with. Also think about your reasons for agreeing or disagreeing. Do you have evidence to support your idea? Do you have evidence to challenge someone else’s idea?”
- Ask questions to gain more understanding of how students are thinking.
- Ask questions to help students better understand their own thinking.
- Ask questions to help students better understand each other’s ideas.

Examples of Questions That Elicit a Variety of Student Ideas

About Earth’s Changing Surface

- Why do you think the surface of Earth isn’t totally flat?
- How would you describe the surface of Earth where you live? Why do you think there are hills in one place and flat areas in another place?
- After a heavy rain, you might see some dirt in the middle of the street. Where did the dirt come from? How did it end up in the middle of the street?
- Sometimes, big bulldozers move soil or dirt from one place to another. Does anything in nature move soil or dirt from one place to another? How do you know?
- Do mountains ever change? Do they ever get taller or shorter?
- Can mountains grow so tall that they reach outer space? Why or why not?

About Energy Transfer

- Where does a marble rolling down a ramp get its energy from?
- Tires get hot when they skid to a stop. Where does that energy or heat come from?
- When a moving object comes to a stop after a collision, what do you think happens to its energy?
- What happens to the light energy in a room when you turn out the light? What happens to the sound energy when you don’t hear the sound anymore?

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 2: Ask Questions to Probe Student Ideas and Predictions

Throughout a lesson, you, as the teacher, should take every opportunity to ask questions that probe student thinking. Probe questions are directed to one student who has already provided an answer or offered an idea. The teacher then follows up with this student to probe his or her thinking. Sometimes a teacher asks a sequence of questions that probe one student's thinking before moving on to another student or another thread or topic. These questions shouldn't introduce new language or science ideas, nor are they intended to change student thinking; rather, the goal is to build on ideas a student has already presented. Probing an individual student's thinking can take place during a whole-class discussion or as students work individually or in small groups.

The purpose of asking questions that probe student thinking is to get more information about a student's understanding of an idea he or she has expressed. It isn't designed to teach new ideas or "lead" students to a correct answer.

A probe question may ask a student to provide more information ("Tell me more.") or clarify his or her thinking ("Did you mean …?"). Like questions that elicit student ideas, questions that probe student thinking can help you learn about students' prior knowledge, misconceptions, experiences, and ways of making sense. The more you can understand how students are thinking about science ideas and phenomena, the better you can adapt your instruction to challenge their misconceptions and support them in changing their ideas toward more-scientific, evidence-based understandings. You have to know what students are thinking in order to challenge and guide their thinking effectively!

Questions that probe student thinking are useful for students as well. When asked questions that probe their thinking, students explore, share, and clarify their own ideas. They also benefit from listening to other students' ideas. Just as you want students to listen to each other's responses when you ask elicit questions, you also want them to listen for ideas they agree or disagree with when you're asking another student a probe question. This gives all students an opportunity to consider ideas, evidence, and reasoning that might challenge their thinking.

When Is Strategy 2 Used?

- After a question designed to elicit student ideas and predictions
- As a follow-up after a question designed to challenge student thinking
- Frequently throughout the lesson

Examples of General Questions That Probe Student Thinking

- Can you tell us more about that?
- What do you mean when you say …?
- Can you tell me more about how you think that happens?
- So you're saying [paraphrase student response]. Can you tell me how I'm getting it wrong?

- Can you tell me how you're thinking about that?
- Can you put that idea into a complete sentence?

Examples of Content-Specific Questions That Probe Student Thinking

About Earth's Changing Surface

Context: Students watch a short video that shows a fast-flowing mountain stream.

T: What do you think is happening to the rocks or soil in the stream? *(Elicit)*

S: The water is going over the rocks.

T: Can you say more about the water and the rocks? (*Probe*)

S: I think the water might move some of the small rocks and some of the dirt at the bottom.

T: You mentioned small rocks. Why do you think the water moves small rocks and dirt but not other rocks in the stream? (*Probe*)

S: The water is going really fast, so it pushes some of the small rocks and the dirt along with it. The water isn't strong enough to push bigger rocks.

About Energy Transfer

Context: The teacher asks students to predict what will happen to one boy's energy when he and his bike collide with another boy on his bike.

T: What do you predict will happen to the energy of Mumford and his bike when he collides with Leroy? *(Elicit)*

S: I think Mumford's energy will disappear.

T: What do you mean "disappear"? *(Probe)*

S: Mumford won't have any energy. His energy goes away.

T: So do you mean that the energy no longer exists? *(Probe)*

S: Well, Mumford will stop moving, so he doesn't have energy.

T: What do you think happened to Mumford's energy? *(Probe)*

S: Maybe it went into Leroy.

T: How might it do that? *(Challenge)*

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 3:
Ask Questions to Challenge Student Thinking

Throughout the lesson, you, as the teacher, should take every opportunity to ask questions that probe and challenge student thinking. Probe questions reveal how students are thinking without trying to change their understandings or ideas. In contrast, challenge questions try to move students toward changing their thinking and developing deeper understandings of science ideas. Thus, challenge questions are designed to push students to think more deeply, to reconsider their thinking, to make a new connection, and/or to use new science vocabulary.

Learning to ask good challenge questions takes time and conscious effort. The goal is to get students thinking harder while also scaffolding or guiding their thinking toward more-scientific understandings.

Care must be taken to avoid questions or hints that lead students to the "right" answer without challenging them to really think. Such leading questions are often posed in a fill-in-the-blank or yes-no format, accompanied with hints that frequently enable students to guess the right answer.

Examples of Leading Questions to Avoid	
About Earth's Changing Surface	**About Energy Transfer**
T: What is underneath the continents and the oceans? S: Earth's core. T: Yes, but something else is closer to the continents. S: Ummmm … T: What do you put your food on when you eat dinner? S: Oh! Plates. T: What kind of plates? S: They move. T: It starts with a *T*. S: Oh yeah, tectonic plates.	T: What happens to Mumford's energy when he collides with Leroy? S: It goes to Leroy. T: Yes, but what is that process called? S: Ummmm … T: We just wrote that word on the board. It starts with a *T*. S: Oh! It transfers.

Questions that challenge student thinking don't ask students to simply state a vocabulary term; rather they push students to use science ideas in a meaningful way. Challenge questions avoid leading directly to the right answer and focus instead on guiding student thinking toward a new concept or deeper understanding. It's not an easy task for us as teachers to shift our focus from helping students get the right answers ("leading") to challenging students to develop or clarify their thinking and reasoning.

When Is Strategy 3 Used?

- Anytime during the lesson *except* when you're trying to elicit students' initial ideas and predictions about a science idea or concept

Examples of General Questions That Challenge Student Thinking

- Can you add some of the new ideas we've been talking about to your explanation?
- Can you explain how that happens?
- Why does that happen?
- How does that relate to the ideas we've been studying?

Examples of Content-Specific Questions That Challenge Student Thinking

About Earth's Changing Surface

Context: You're observing two students work with two pieces of foam representing Earth's tectonic plates. Student discuss what happens when they push the pieces together.

T: What are you observing? *(Elicit)*

S1: When we push the foam pieces together, they both push up.

T: Can you connect this observation with our discussions about how Earth's surface changes? *(Challenge)*

S2: I think it shows how mountains form.

T: What makes you think so? *(Probe)*

S2: Because the foam pieces are like plates on Earth. When plates push together on Earth, mountains are pushed up.

T: Tell me more about how you're thinking about that. *(Probe)*

S2: Well, the surface of Earth is divided into different pieces called *plates*. Heat from inside Earth makes the plates move, but they move different directions, so sometimes they crash into each other.

T: In what ways are the foam pieces different from what happens on Earth's surface? *(Challenge)*

S1: Hmm, well, Earth's surface isn't made out of foam.

T: Any other differences? *(Challenge)*

S2: Well, when we pushed the foam pieces together we made a "mountain" really quickly, but in real life, the plates move very, very slowly.

About Energy Transfer

Context: Three students are working to test their ideas about what will happen to a stationary marble at the bottom of a ramp when a marble rolling down the ramp collides with it. The students make predictions about how the speeds change after the collision and relate this to energy and energy transfer.

T: What are you observing? *(Elicit)*

S1: We saw the marble speed down the ramp and collide with the marble at the bottom of the ramp.

S2: The marble at the bottom of the ramp started to move, so it got some energy.

T: What do you mean "it got some energy"? *(Probe)*

S2: Well, the marble must have had the energy inside or something, so it got it and used it to move.

T: Could the energy have come from somewhere else? Could the marble get it from somewhere else? *(Challenge)*

S2: Hmm, I don't know. Maybe.

T: Can you describe the energy of the marble rolling down the ramp and colliding at the end of the ramp? *(Challenge)*

S2: The marble speeded up down the ramp, so it was getting more and more energy. When it collided with the other marble, it slowed down, and the other marble speeded up. Oh! Maybe the energy moved from the first marble to the second marble!

T: You said before that the marble got its energy from inside. Do you still think that? *(Probe)*

S2: No.

T: Tell me what you think now and why you think that way. *(Probe)*

S2: I think the second marble got its energy from the first marble when they collided. I think that because the first marble slowed down and stopped after the collision, and the second marble started to move after the collision.

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 4:
Engage Students in Analyzing and Interpreting Data and Observations

Overview of Student Thinking Lens Strategies 4–7

Strategies 1–3 focus on types of *questions* teachers can ask to reveal and challenge student thinking. Strategies 4–7 focus on four types of *activities* that can reveal and challenge student thinking:

- Engage students in analyzing and interpreting data and observations.
- Engage students in constructing explanations and arguments.
- Engage students in using and applying new ideas in a variety of ways and contexts.
- Engage students in making connections by synthesizing and summarizing key science ideas.

In each of these types of activities, students should be asked questions that probe and challenge their thinking.

We'll focus now on what it means to engage students in analyzing and interpreting data and observations.

Analyzing and interpreting data is one of eight scientific practices identified in the *Next Generation Science Standards* (NGSS Lead States, 2013) as essential in elementary science classrooms. This practice is important because observations and raw data have little meaning on their own. But when they are organized and represented in a variety of ways, the result reveals or communicates different aspects of the data. In some instances, students record data in a table as they collect it, but they need to graph the data to reveal a pattern. In other instances, students need to observe a physical representation of a natural phenomenon or draw pictures of what they see to make sense of something in their world.

When students *organize* data, they may construct tables, graphs, or diagrams. When they *analyze* data, they identify patterns, find similarities and differences, or use statistical analysis, such as finding an average (i.e., a mean, median, or mode). When students *interpret* data, they bring meaning to the patterns they identify and find relationships using science ideas and knowledge/data in their experiences. They connect observations or patterns to science ideas or use data and observations to answer a question. Analysis and interpretation bring out the meaning of data—and their relevance—so that students can use it as evidence to construct an explanation or engage in argumentation.

Students need support in learning how to organize, present, and analyze data in ways that will reveal patterns and relationships. As with analysis and interpretation, patterns also help students make sense of data and observations so they can use this information as evidence in constructing explanations of phenomena.

How can you help students learn to *organize* data and observations?

- Make sure students can distinguish between an observation and an interpretation or idea about what the observation might tell them about how the world works.
- Help students record their data and observations accurately using words, drawings, numbers, or combinations of these.
- Provide feedback to help students communicate their observations clearly and completely. Some teachers require students to speak and write in complete sentences whenever they share their observations and ideas.

How can you help students learn to *analyze and interpret* data and observations?

- Encourage students to look for patterns in their data and observations.
- Teach students how to find patterns by organizing and presenting data and observations in forms that will help them see this information in new ways. It's important to teach students how to create and interpret these different forms, emphasizing how they can help reveal patterns in data. These forms include the following:
    - Drawings
    - Charts
    - Tables
    - Diagrams
    - Venn diagrams
    - Different kinds of graphs
- Have students share data and observations with the class to identify patterns. This allows students to draw on a larger set of data and observations from which clear patterns and trends, as well as exceptions in the data, may become more visible.
- Computers, digital tools (e.g., sensors, animations, databases, and spreadsheets), and mathematics can sometimes help students see patterns that will support their analyses and interpretation of data. But don't use these tools just because they're "cool." Make sure they'll help students develop richer scientific understandings of the learning goals. When deciding whether to use these tools, ask yourself the following questions:
    - Do these tools support students in collecting and/or making meaning of their data in age-appropriate ways that are consistent with the lesson's science content storyline?
    - Are these tools interesting and engaging but potentially distracting from the storyline and intended learning?

When Is Strategy 4 Used?

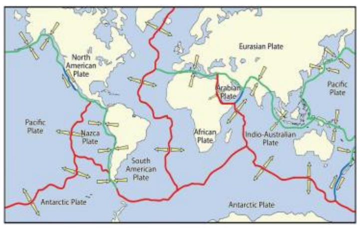
- Anytime during the lesson when students are investigating phenomena and/or scientific models
- To help develop student understandings of new science ideas
- As an opportunity for students to apply new science ideas in order to make sense of a new set of data or observations

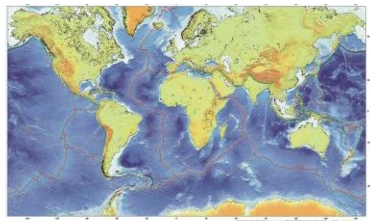
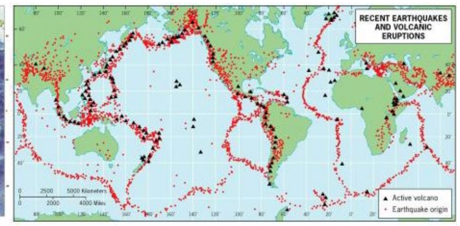
- When students are learning to communicate in scientific ways (See Student Thinking Lens strategy 8: Engage students in communicating in scientific ways.)

Examples of Analyzing and Interpreting Data and Observations

About Earth's Changing Surface

- Students use a relief map of the United States to identify patterns in landforms, including similarities and differences among the types of landforms that exist in the US.
- Students analyze data across three different world maps (one with plate boundaries, one with physical features, and one with the occurrence of earthquakes and volcanoes) to identify patterns that help provide evidence of plate tectonics.



- Students write about their observations of weathering after viewing several photos of tree roots breaking apart rock over time.
- Students record changes in erosion and deposition using different angles of stream tables to identify what about stream slope might promote or slow down erosional processes.

About Energy Transfer

Context: Students are rolling a marble down ramps with different angles of incline and seeing how that affects speed and how far the marble will move a small block of Styrofoam. They're trying to figure out the relationships between the angle of incline, the speed of the marble, and the marble's energy. They create two graphs, one showing the angle of the ramp and the speed of the marble, and the second showing the angle of the ramp and the distance the marble moved the Styrofoam.

S1: The marble on the first ramp moved the Styrofoam the farthest distance. I think it did that because it was moving faster. The first graph shows that the steepest ramp had the fastest marble, and the second graph shows that the steepest ramp moved the Styrofoam the farthest.

S2: Yeah, the faster-moving marble was on the steepest ramp, so it was higher off the ground to start with. I think that's why it was moving faster when it hit the Styrofoam. I think being higher off the ground might give the marble more energy because of gravity.

S1: The marble that was higher must have had more energy, and we have two good pieces of data to support that. Graph 1 showed the marble moved faster, and graph 2 showed it moved the Styrofoam the farthest distance.

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 5:
Engage Students in Constructing Explanations and Arguments

The job of a scientist is to come up with ideas that help explain aspects of the world, such as why energy transfers from one object to another object in a collision, and how mountains are formed when Earth's plates collide. Likewise, students studying science should learn to construct scientific explanations to help them make sense of their world. As students construct explanations, they

- deepen their understandings of important science ideas;
- create an account of *why* events happen, not merely descriptions of *what* happened;
- speculate about things they cannot directly observe (things that are too small, like atoms; too slow, like mountain building; too quick, like electricity moving through a circuit; or too abstract, like gravity); and
- use evidence from data and observations to create logical reasons that support their ideas.

Arguments in science play an important role in this explanation-building process. Scientific arguments aren't the same as arguments in everyday situations. In science, arguments are conversations used to justify and support new ideas and address questions about the design of experiments and the interpretation of data. Through argumentation, scientists question one another with the goal of coming to a shared understanding that is plausible and supported by evidence—not merely to convince each other that they are right. As students engage in scientific argumentation, they also engage in classroom conversations to

- justify and defend explanations using evidence and logical reasoning,
- compare competing explanations,
- evaluate the way an experiment was designed or how data was interpreted to identify weaknesses and limitations of proposed explanations, and
- determine whether proposed explanations fit the data and are reasonable based on other experiences in the world.

Explanation and argumentation depend on each other in science. Students engage in argumentation as they work to construct, defend, and evaluate explanations of various phenomena or events. In this discussion, we'll consider each practice separately and then provide some classroom examples to demonstrate how they work together to help students deepen their understandings of science ideas.

Constructing Explanations

Constructing explanations is one of the eight essential science practices for K–12 science education defined in the *Next Generation Science Standards* (NGSS Lead States, 2013). Scientific explanations create a storyline of *why* observable events happen. They're often used to predict future events or make inferences about past events. However, scientific explanations aren't storylines that emerge from our imaginations. They are logical, supported by data and observations, and link new ideas to established scientific concepts.

A description of one student's experience in science class might help you better understand scientific explanations. Rachel was a 5th-grade student in a hands-on science classroom where the class had been growing plants in the light and the dark, making careful observations and measurements over the course of a month. Rachel created beautiful graphs and detailed descriptions of her plants. She was a careful observer. But at the end of the unit, she was frustrated: "It was fun at first. But I always knew plants needed light and now I know it again." All that measuring and observing didn't lead her to any new understandings about plants. The entire activity led her to a description about *what* happened without any new understanding of *why* it happened.

Generating explanations involves *logical thinking*, using *science ideas* to make sense of *evidence* in the form of observations and data:

Constructing explanations = Logical thinking + Science ideas/theories + Evidence

How can we best help students engage in reasoning to construct and understand scientific explanations? To support this kind of work, an atmosphere needs to be created that welcomes students' genuine ideas and their efforts to build explanations from evidence rather than the more typical search for what the teacher wants to hear.

A useful framework for guiding students in their construction of explanations was developed in the *Investigating and Questioning Our World through Science and Technology* curriculum (Krajcik & Reiser, 2004), which emphasizes three aspects of constructing scientific explanations: claim, evidence, and reasoning (CER). We have modified this framework to emphasize the central role of science ideas in scientific reasoning and clarify what is involved. Following is a description of each step using language from Krajcik and Reiser, as well as our added language (in italics).

- **Claim:** What happened, and why do you think it happened? A claim is a statement that answers a question we are investigating.
- **Evidence:** What information or data or observations support your claim?
- **Reasoning:** *How can you use **logic** and **science ideas** to explain the evidence and support your claim? What science ideas (theories) can you use to help make sense of this evidence? How can you use linking words to help you connect your claim, evidence, and reasoning?*

As students use the claim, evidence, and reasoning framework, they learn how to build explanations by thinking through the science ideas and evidence.

Constructing Arguments[1]

Scientists work hard to set aside their beliefs and biases and focus instead on what they actually see in their data and observations. But this isn't always easy because different explanations can be given for the same evidence. Consequently, scientists must critically evaluate the logic of the reasoning as well as the evidence used in building any explanation. Scientists present arguments to make the case for their proposed explanations. In response, other scientists use arguments to identify a claim's weaknesses and limitations. Argumentation is also needed to resolve questions involving the best experimental design, the most appropriate techniques of data analysis, or the best interpretation of a data set.

[1]This section draws heavily from *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas* (pp. 71–74) by the National Research Council (NRC), 2012, Washington, DC: National Academies Press.

Even very young students can begin constructing their own arguments to explain data and observations. But the teacher needs to support students by creating conditions where they actively listen and respond to one another, as well as a classroom culture that encourages them to make sense of events and phenomena rather than merely restating ideas from a textbook or the teacher. STeLLA Student Thinking Lens strategy 8—Engage students in communicating in scientific ways—provides language you can use to introduce students to the argumentation process:

- Think of an idea, claim, and explanation.
- Give a reason or evidence for your idea.
- Listen to others' ideas and ask clarifying questions, agree or disagree with others' ideas, or add onto someone else's idea.
- Suggest an experiment or activity to get more evidence.
- Let your ideas grow and change.

In addition, strategy 8 provides sentence starters that students can use to support developing their argumentation ability:

- *My idea is …*
- *My evidence is …*
- *I agree/disagree because …*
- *I want to add onto what _______ said.*
- *We could get better evidence if …*
- *I want to change my idea …*

When Is Strategy 5 Used?

- Anytime during the lesson when students are reasoning about observations and other forms of data, communicating to reach a common understanding of the science content storyline, and making links between their observations and science ideas.

Examples of Constructing Explanations and Engaging in Scientific Argument

About Earth's Changing Surface

Context: In this example of Earth's changing surface, students identify patterns in the data and make connections between their data and science ideas. Students study a world map that shows the locations of current earthquake and volcanic activity. Their task is to describe the pattern they observe and develop an explanation for the pattern. Students are expected to draw from their knowledge about tectonic plates to make sense of the data.

S1: The pattern I see is that all the volcanoes shown on the map seem to be in exactly the same place as the boundaries between tectonic plates. We learned that Earth's crust is made of moving plates, and when the plates collide, that's where earthquakes and mountain building happens. So we see on the map that all the earthquakes and volcanoes are in, like, a row or a string, so I think that's like the edge between two tectonic plates that pushed together. *(Reasoning with evidence and science ideas)*

S2: I sort of agree and sort of disagree. The edges of all the plates can't just push together everywhere. That doesn't make sense. Here in the Atlantic Ocean where there are so many volcanoes in a long row, I think that's one place two plates must pull apart, and the mountains form because lava is coming out of the space between the plates. And then over here, along Japan and China, that's a plate edge where two plates come together. The pattern is that mountains form at plate boundaries, but sometimes that's because the plates are pushing together, and sometimes they're moving apart. *(Reasoning with evidence and science ideas)*

About Energy Transfer

Context: Students are writing explanations to answer the question, *Where does the energy come from for Mumford to move down the hill?* Teams of students record their explanations on chart paper. The teacher chooses two explanations and posts them at the front of the room. The teacher reminds students that the purpose of looking at the explanations is for everyone to understand the science ideas and improve all the explanations.

Team 1's explanation: Mumford made his own energy to move down the hill by pedaling. He stopped moving at the bottom of the hill because he stopped pedaling. *(Weak explanation with a claim but no evidence or reasoning)*

Team 2's explanation: The energy that Mumford got to go down the hill was because he was on top of the hill. Just like a rock can fall from the top of a ledge, Mumford could go down the hill without pedaling because he was at the top. *(Stronger explanation with a claim, evidence, and reasoning)*

Next, the teacher guides students through argumentation:

T: After you've read each explanation, think of one question you want to ask the team. Write it down in your notebooks and be prepared to ask and answer questions.

S1: I have a question for Team 1: I think Mumford was moving down the hill *without* pedaling his bike. Isn't that what it said in the story?

Team 1: I don't think we know if he was pedaling or not, but he *could* have been pedaling his bike, and that would make him move down the hill.

S1: But in this picture, it looks like Mumford is coasting and not pedaling. And if you're at the top of a hill, you don't have to pedal to move down the hill.

Team 1: You're right he isn't pedaling. We'll have to think about this some more.

S2: I have a comment for Team 2. We just learned that to have energy, an object has to be moving. You say that Mumford got the energy to move because he was at the top of the hill. But Mumford wasn't moving at the top of the hill.

Team 2: We learned that to have *motion energy*, an object has to be moving. That's *kinetic energy*. Mumford had *potential energy* at the top of the hill, not kinetic energy.

S2: I think your explanation would be clearer if you added that science idea.

Team 2: Good idea!

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 6: Engage Students in Using and Applying New Science Ideas in a Variety of Ways and Contexts

After students encounter new science ideas, they need the opportunity to practice using them and to see their usefulness in explaining a variety of phenomena. Too often, we as teachers expect students to hear a new idea and then immediately understand and be able to use it in a scientifically accurate way. This is one of the most common mistakes in science teaching and learning—we simply don't give students enough opportunity and time to wrestle with new ideas that are often in conflict with their personal ideas and theories. Research shows that the process of meaningful conceptual learning is a messy one in which students often cling to their personally sensible ideas and have difficulty changing their ideas and ways of thinking even after learning about contradictory evidence, scientific explanations, and scientific ways of thinking.

To learn ideas that are often abstract and difficult, students need multiple opportunities to use them in a variety of situations before they really make sense of the ideas and develop a meaningful conceptual understanding. When students are challenged to explain a new real-world situation they haven't encountered before, at first they'll fall back on prior knowledge and misconceptions to explain the situation. Only with practice in explaining a variety of real-world situations, as well as careful support and guidance from the teacher, will they become comfortable and successful using new science ideas to explain new scenarios and phenomena. As students start internalizing new science ideas, they will need less and less guidance and support from others and will develop a deep conceptual understanding they can use to reason about different situations.

Activities that challenge students to use and apply new ideas go beyond asking students to repeat knowledge they've learned or memorized (e.g., "What is energy?"). Use-and-apply activities require students to think, reason, and make sense of science ideas to explain new situations. Students must connect the ideas they're learning to new scenarios, situations, or phenomena, and they must make connections among science ideas.

Use-and-apply activities come in different forms, each of which is most effective if it requires students to put at least two ideas together and respond in one or more complete sentences. Following are examples of activities that challenge students to use and apply new ideas:

- Explaining a new situation or phenomenon.
- Making predictions.
- Making sense of new observations or experimental data.
- Creating synthesis diagrams or concept maps.
- Designing a solution to a practical problem.

Don't Worry!

As the previous list indicates, sometimes an investigation that engages students in analyzing and interpreting data and observations (strategy 4) can be used as an opportunity for students to use and apply new ideas (strategy 6). As you'll learn shortly, synthesizing and summarizing activities (strategy 7) can also provide opportunities for students to use and apply new ideas.

Don't worry about how to classify a particular activity. Just make sure to be clear about your purpose for an activity. Are you using a firsthand investigation to help students encounter and begin developing a new idea or to give students a chance to practice using new ideas they've already encountered but not yet mastered? The most important thing is this: *Give students many opportunities to think, reason, and explain; make connections; and practice using new ideas in multiple contexts.*

Teachers sometimes pose use-and-apply questions to assess student learning at the end of a unit of study. While such questions make excellent and challenging assessment tasks, don't wait until the end of a unit to pose them. Students need multiple opportunities to practice using new ideas in a variety of contexts in order to *develop* a deep understanding of the concepts. That is, use-and-apply activities are an essential (and often underused) part of the learning process. If students have the opportunity to really make sense of new ideas through a number of different use-and-apply experiences, they will develop understandings that enable them to successfully tackle use-and-apply test questions at the end of the unit or school year.

When Is Strategy 6 Used?

- *After* students have encountered new science ideas
- *Before* the final unit assessments

Examples of Using and Applying New Ideas

About Earth's Changing Surface

Scenario 1: Students have been studying weathering and erosion as processes that shape the surface of Earth. The teacher gives photographs to the students, and they work in pairs to complete the following tasks:

1. **Utah's Arches National Park:** Students are asked to explain what processes might have formed the arches, and how those processes changed the landscape. They also discuss whether these processes happen slowly or quickly in changing the surface of Earth.
2. **Pikes Peak (in the Rocky Mountains) and Mount Katahdin (in the Appalachians):** The students' task is to answer the following questions: For each of these mountains, do you think weathering and erosion are occurring? If yes, explain how that is happening. If no, explain why not. Why do you think the two mountains look so different?

Scenario 2: As students walk around the school grounds, their task is to find evidence of any erosion, weathering, or uplift. They draw or take pictures of the examples they find. Back in the classroom, they write about their findings using the scientific terminology they've learned (e.g., erosion, weathering, uplift) and providing evidence and reasons to support their claims.

About Energy Transfer

- Students have been "energy detectives" in earlier lessons and activities, and now they watch as their teacher demonstrates a hand-crank flashlight. Their task is to draw an energy-flow diagram with arrows showing energy transfers and transformations in the system. Then they'll record different ways they're able to detect energy (i.e., motion, sound, light).

- Student teams are given a bag of objects (such as a regular flashlight, a windup toy, and a noisemaker). They must choose one object and draw an energy-flow diagram for that object. Then they share ideas with their team as they describe the ways that energy changes in their system.

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 7: Engage Students in Making Connections by Synthesizing and Summarizing Key Science Ideas

Many times, the teacher or the textbook does all the organizing and synthesizing of the science content, and the students are simply expected to absorb the information. However, students will be challenged to think and reason and make sense of science ideas if they're given the task of synthesizing and summarizing the ideas, evidence, and experiences they've encountered in lessons or units.

One way to engage students in this work is to ask them to write a summary at the end of the lesson (either individually or in small groups). To support students in constructing meaningful summaries, you can scaffold this work (especially at first) by giving them key words to use in their summaries, requiring them to write a certain number of sentences, or providing a sentence starter, among other possibilities. Whole-class discussion of these student summaries can then be used to highlight key ideas.

Synthesis activities involve teachers and students in pulling together various new ideas—in making connections and synthesizing ideas. In fact, sometimes the entire lesson is focused on a synthesis activity. For example, toward the end of a series of lessons about Earth's changing surface, the teacher might have students work in small groups to create and present a diagram that compares processes that build up Earth's surface with processes that wear it down. Or at the conclusion of a lesson in which students have investigated the idea that faster-moving objects rolling down a ramp have more energy, students are required to synthesize and summarize relationships between both the height at which the object started (or the angle of the ramp) and speed, and speed and energy.

Synthesis work can take a variety of forms. For example, students could write a unit synthesis of ideas, or they might create visual representations, such as concept maps, diagrams, Venn diagrams, models, charts, or role-plays. A true synthesis task that will make students' understandings (and confusion) visible doesn't simplify the task by allowing students to repeat memorized information. Instead of giving students a diagram to label, for example, the teacher might give them a blank sheet of paper to create their own diagrams and then have them explain their diagrams to others to elaborate the meaning behind them.

When Is Strategy 7 Used?

- After students have encountered new science ideas and/or observations, usually at the end of a lesson or after a series of lessons on related content.

Examples of Synthesizing and Summarizing Key Science Ideas

About Earth's Changing Surface

1. At the end of a lesson about weathering and erosion, the teacher asks students to look at images of two mountain ranges—the Appalachian Mountains in the eastern US and the Rocky Mountains in the western US. The teacher notes that the Appalachian Mountains are significantly lower in elevation and less jagged than the Rocky Mountains. Then the teacher asks students to describe how weathering and erosion might have contributed to the differences they observed between the two mountain ranges.

2. At the end of a series of lessons about weathering and erosion, the teacher provides students with a model or diagram of a watershed. Students are to use the vocabulary they developed during the unit to label the model/diagram and show
   a. how water moves through the model or diagram,
   b. where Earth materials might be weathered or eroded, and
   c. where those Earth materials would be deposited as the water flows through the watershed.
3. Students have examined a hard-boiled egg as a model of Earth and talked about Earth's crust, mantle, and inner and outer cores as they relate the egg to planet Earth. To synthesize students' understandings, the teacher asks students to write answers to these questions:
   a. How does the shell of the egg compare with Earth's crust? In what ways is the eggshell like Earth's crust? In what ways is it different?
   b. How does the white of the egg compare with Earth's mantle? In what ways is the egg white like Earth's mantle? In what ways is it different?
   c. How does the yolk of the egg compare with Earth's core? In what ways is the egg yolk like Earth's core? In what ways is it different?
   d. Do you think a hard-boiled egg is a good model of Earth? Why or why not?

About Energy Transfer

- After students have read a story about a boy coasting down a hill on his bike and made connections between the story and an activity with marbles rolling down a ramp, they summarize and synthesize their learning by using the terms *gravity*, *kinetic energy*, and *potential energy* in at least three sentences describing the ways energy changed in the story and the activity.
- After drawing and discussing their energy-flow diagrams showing the energy transfers and transformations that occur in various objects (e.g., a battery-operated device, a windup toy, or a noisemaker), students write captions for their diagrams.

Strategies to Reveal, Support, and Challenge Student Thinking

STeLLA Strategy 8:
Engage Students in Communicating in Scientific Ways

Students' thinking will be revealed more clearly as they learn to think and communicate using scientific norms of discourse. In other words, students should learn to think and communicate in scientific ways, though they may not always use scientific terminology. Scientific discourse centers on a particular argumentation pattern that values the use of evidence, coherent reasoning, and consistent explanations with supporting data. Scientists expect skepticism and challenging questions in response to their ideas. Students can adopt such scientific discourse and use it to propose ideas or explanations, support ideas with evidence, ask challenging questions, and agree or disagree with their classmates' ideas.

The National Research Council convened a prestigious panel of expert science-education researchers, teachers, scientists, and cognitive psychologists, who issued a report emphasizing the importance of helping elementary students learn to participate and communicate productively in science (NRC, 2008). Their description of this strand of scientific proficiency highlights the importance of engaging students in

- learning how to communicate effectively in a scientific community in the classroom,
- understanding the norms for presenting scientific arguments and evidence, and
- practicing productive social interactions with peers in the context of classroom science investigations.

The panel concluded that, like scientists, "science students benefit from sharing ideas with peers, building interpretive accounts of data, and working together to discern which accounts are most persuasive" (NRC, 2008, p. 21). However, before they can be effective in this new way of interacting with one another, students need to learn about scientific argumentation and how it differs from arguments more familiar to them, such as those that occur on the playground. Scientific ways of thinking and communicating don't just develop as students engage in science activities; they need to be explicitly taught. Explicitly teaching students about scientific practices and communication will help them better understand the nature of science and improve the clarity, precision, and elaboration of their ideas.

Such explicit instruction about scientific ways of communicating is also essential in addressing the diverse student populations in our schools. While many students learn about scientific ways of thinking at home and in extracurricular activities, some students grow up in cultures and environments where different ways of thinking are highly valued and emphasized; others grow up in more insular environments where expressing differing viewpoints is actively discouraged. These students need to learn about scientific ways of thinking and communicating in order to understand and be successful in a new cultural setting—the scientific community.

The *Next Generation Science Standards* (NGSS Lead States, 2013) represent a national consensus that science education should help K–12 students learn core science ideas and crosscutting concepts through the use of eight essential scientific practices:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data

5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

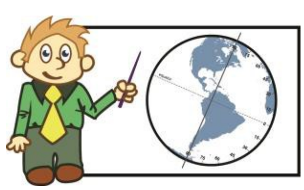
These practices represent a much richer view of scientific activity than the "scientific method," the widely accepted but overly simplistic view of science. The NGSS science practices present a more accurate view of science as focusing on evidence and argument in building and using models and in generating explanations to make sense of phenomena. The STeLLA strategy of communicating in scientific ways supports students in learning about and using these eight science practices. The purpose of strategy 8 is to help you explicitly teach elementary students how to develop these practices. The following chart shows the relationship between the STeLLA descriptors for communicating in scientific ways and the science practices defined in the NGSS. The STeLLA language is designed to be more accessible to K–12 students.

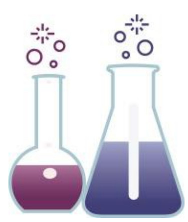
<table>
<tr><th></th><th>STeLLA
Communicating in Scientific Ways</th><th>Next Generation Science Standards:
Science Practices</th></tr>
<tr><td>1.</td><td>Ask why and how questions.</td><td>Asking questions</td></tr>
<tr><td>2.</td><td>Observe.</td><td rowspan="2">Analyzing and interpreting data
Using mathematics and computational thinking</td></tr>
<tr><td>3.</td><td>Organize data and observations.</td></tr>
<tr><td>4.</td><td>Think of an idea, claim, prediction, or model to explain your data and observations.</td><td rowspan="3">Developing and using models
Constructing explanations</td></tr>
<tr><td>5.</td><td>Give evidence for your idea or claim.</td></tr>
<tr><td>6.</td><td>Reason from evidence or models to explain your data and observations.</td></tr>
<tr><td>7.</td><td>Listen to others' ideas and ask clarifying questions.</td><td rowspan="3">Engaging in argument from evidence</td></tr>
<tr><td>8.</td><td>Agree or disagree with others' ideas.</td></tr>
<tr><td>9.</td><td>Add onto someone else's idea.</td></tr>
<tr><td>10.</td><td>Search for new ideas from other sources.</td><td rowspan="2">Obtaining, evaluating, and communicating information</td></tr>
<tr><td>11.</td><td>Consider whether new ideas make sense.</td></tr>
<tr><td>12.</td><td>Suggest an experiment or activity to get more evidence or to answer a new question.</td><td>Planning and carrying out investigations</td></tr>
<tr><td>13.</td><td>Let your ideas change and grow.</td><td></td></tr>
</table>

Examples of Ways to Engage Students in Communicating Scientifically

The following Communicating in Scientific Ways chart can be used to teach elementary students about scientific practices and communication. This tool connects what scientists *do* with the kind of talk they use to *communicate about* what they do. When used frequently, this chart can help you support students in improving their abilities to engage in scientific practices and communication.

STeLLA: Communicating in Scientific Ways

What a Scientist Does	Symbol	What a Scientist Says
1. Ask why and how questions.		How come …? I wonder … Why …? How do they know that …?
2. Observe.		I see … I noticed … I recorded … I measured …
3. Organize data and observations.		I see a pattern … I think we could make a graph … Let's make a chart …
4. Think of an idea, claim, prediction, or model to explain your data and observations.		My idea is … I think that … We could draw a picture to show … I think it looks like this …
5. Give evidence for your idea or claim.		My evidence is … The reason I think that is … I think it's true because …
6. Reason from evidence or models to explain your data and observations.		The reason I think my evidence supports my claim is because … The model shows that …

What a Scientist Does	Symbol	What a Scientist Says
7. Listen to others' ideas and ask clarifying questions.		Are you saying that …? What do you mean when you say …? What is your evidence? Can you say more about …?
8. Agree or disagree with others' ideas.		I agree with _______ because … I disagree with _______ because …
9. Add onto someone else's idea.		I want to piggyback on _____'s idea. I want to add onto what _____ said.
10. Search for new ideas from other sources.		We could get some new ideas from …
11. Consider whether new ideas make sense.		That idea makes sense to me because … That idea doesn't make sense because … What's their evidence?
12. Suggest an experiment or activity to get more evidence or to answer a new question.		What if we …? We could get better evidence if we …
13. Let your ideas change and grow.		I think I'm changing my idea. I have something to add onto my idea.

Summary of STeLLA Student Thinking Lens Strategies

	Strategy	When	Purpose
Questions That Reveal and Challenge Student Thinking	Ask questions to elicit student ideas and predictions.	When a new idea is going to be introduced Before a new learning goal is developed	To reveal students' initial ideas, predictions, misconceptions, and experiences
	Ask questions to probe student ideas and predictions.	Anytime	To reveal more about a given student's current thinking
	Ask questions to challenge student thinking.	As part of developing the learning goal (not when eliciting students' initial ideas)	To challenge student thinking in the direction of the learning goal To help change student thinking about the science ideas
Activities That Challenge Student Thinking	Engage students in analyzing and interpreting data and observations.	As part of developing the learning goal or after a learning goal has been developed (as a use-and-apply activity)	To teach students how to organize, present, and analyze data in ways that will reveal important patterns and relationships that can be used in developing explanations
	Engage students in constructing explanations and arguments.	As part of developing the learning goal or after a learning goal has been developed (as a use-and-apply activity)	To engage students in using evidence and science ideas to explain observations and data and to develop arguments that assess the strengths and weaknesses of competing explanations
	Engage students in using and applying new science ideas in a variety of ways and contexts.	After the learning goal has been developed Before the final unit assessment	To engage students in using newly learned science ideas to explain new situations, new phenomena, and new real-world connections To demonstrate the wide usefulness and value of the new ideas
	Engage students in making connections by synthesizing and summarizing key science ideas.	After the learning goal has been developed	To engage students in making connections among ideas, evidence, and experiences they have encountered in the lesson(s)
	Engage students in communicating in scientific ways.	Anytime	To engage students productively in science practices and discourse

Strategies to Create a Coherent Science Content Storyline

Introduction to the Science Content Storyline Lens

You've probably encountered science textbooks packed with a wealth of science content. Science textbooks are sometimes so loaded with information that it's difficult to unearth and understand the big ideas that might tie all the facts together. It may seem to you that the solution to this problem is to throw out the textbooks and teach science only through hands-on activities. However, research shows that *hands-on doing* does not automatically lead to *minds-on learning.* Teachers may present accurate science content and engaging hands-on activities, but these content ideas and activities often aren't carefully woven together to tell a coherent story. Students miss the point of the activities they're carrying out and instead pick up random pieces of scientific terminology without fitting the ideas together to develop rich conceptual understandings.

To help students develop more meaningful understandings, you can use the Science Content Storyline Lens to focus attention on how the science ideas in a lesson (or unit) are sequenced and linked to one another to build a coherent "story" that makes sense to students.

What Is a Science Content Storyline?

A science content storyline consists of carefully chosen and sequenced science ideas that build on one another to illustrate a bigger picture (a big idea, a core science idea, or a crosscutting concept). This coherent set of science ideas creates a story within a lesson, as well as across lessons and units. The ideas flow from one to the next so that students can make the connections, just as they can follow and make sense of a good story. The central ideas of the story are emphasized, connected, and linked. Details are used to support the development of the central storyline but are kept to a minimum so they don't clutter and detract from the storyline.

There are two key points to keep in mind regarding coherent science content storylines. First, the storyline is about the *science ideas* in the lesson and how they are organized to tell a story about one big idea or crosscutting scientific concept. Second, the *activities* students carry out in the lesson and unit must engage them in making sense of this science content storyline, with the science ideas and terms explicitly linked to the activities. Thus, each activity helps develop a key part of the science content storyline.

Why Is the Science Content Storyline Lens Important?

Looking at lessons through the Science Content Storyline Lens can help you identify places where students are likely to get confused because of gaps in the storyline, too much distracting information, or activities that aren't clearly linked to the science ideas. It also highlights exactly what knowledge students have access to during the lesson that will help them make sense of the main ideas.

Research results from the 1999 Third International Mathematics and Science Study (TIMSS Video Study) of 8th-grade science teaching in five countries (Roth et al., 2006) illustrate the importance of a clear science content storyline in a lesson. The video study found that US science lessons engaged students in carrying out a variety of activities. In contrast with higher-achieving countries, however, the science activities in US lessons were often used without clear links to the science ideas they might illustrate or support. In fact, more than 25% of the randomly selected US science lessons were almost entirely activity focused, with little or no explicit teaching of science-content ideas. Students simply followed directions and carried out activities without being required to think about scientific explanations or engage in scientific reasoning. In higher-achieving countries, however, lessons were structured to build a clear, coherent science content storyline. All parts of the lesson, including hands-on activities, were closely linked and used to build a story about one science concept.

A Framework for K–12 Science Education (NRC, 2012) also emphasizes the importance of helping students develop a "coherent … understanding of science" (p. 25). But many students leave their science classes holding "disconnected and even contradictory bits of knowledge as isolated facts" (p. 25), which they quickly forget when the test or the course is over. Students typically experience science as a sequence of discrete chapters or units and miss the important connections among the ideas in these chapters/units that will help them deeply understand key concepts. Students often view each day's lesson as linked to the previous only by topic, not by an overarching question or crosscutting concept. They don't expect that ideas and activities experienced in a unit or chapter at the beginning of the school year will have much at all to do with a unit or chapter studied in the spring.

Research shows that we can do better as science teachers by helping students develop deeper understandings of core principles that they can use to "make sense of new information or tackle novel problems," as experts do (NRC, 2012, p. 25). According to the National Research Council (2012), "Research on learning shows that supporting development of this kind of understanding is challenging but aided by explicit instructional support that stresses connections across different activities and learning experiences.… To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months" (pp. 25–26).

What Is Challenging about Developing a Coherent Science Content Storyline?

Developing a coherent science content storyline is especially challenging when you engage students in using scientific-inquiry practices. Students can be actively engaged in predicting, observing, and manipulating materials without making any connections to science ideas and explanations—that is, students can be busily *doing* the activity without thinking about and learning from it. But this isn't how science works. Scientists don't predict and observe without thinking about and making connections to what they already know. Instead, they use scientific practices and the science ideas they already grasp to develop better understandings of important ideas and phenomena. This idea-focused work is what students should do in their science-inquiry activities as well. Otherwise, they'll develop the misconception that science is all about measuring, observing, and predicting and miss the point that the essence of science is about using those practices to build better understandings and explanations of phenomena in the world around us.

Developing a coherent science content storyline is also challenging when you're simultaneously using a Student Thinking Lens to make student thinking visible in the lesson. How will you weave the student ideas that arise during the lesson into your planned science content storyline? Your goal should be to use students' ideas to shape how the science content storyline unfolds (within and across lessons). Before teaching, therefore, you need to anticipate student ideas that might arise and determine how those ideas will affect the science content storyline. While teaching, you must make meaningful adjustments to the planned science content storyline as a result of student ideas that emerge.

What Strategies Support the Planning and Teaching of a Coherent Science Content Storyline?

In this section, we'll examine the following planning and teaching strategies that help create a coherent content storyline within and across science lessons:

- Identify one main learning goal.
- Set the purpose with a focus question or goal statement.

- Select activities that are matched to the learning goal.
- Select content representations and models matched to the learning goal and engage students in their use.
- Sequence key science ideas appropriately.
- Make explicit links between science ideas and activities.
- Link science ideas to other science ideas.
- Highlight key science ideas and focus question throughout.
- Summarize key science ideas.

Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy A: Identify One Main Learning Goal

Research suggests that science lessons often contain too many science ideas, and that these ideas are presented as a list of facts to memorize rather than a big idea or concept that is useful in explaining and predicting the outcome of events in the world around us. Teachers may present accurate science ideas and engaging hands-on activities, but they may be either too numerous or not carefully woven together to create a coherent story. As mentioned earlier, students often miss the point of the activities they're carrying out and instead pick up bits and pieces of scientific terminology without fitting the ideas together to develop rich conceptual understandings.

The Science Content Storyline Lens focuses attention on how the science ideas in a lesson are sequenced and linked to one another and to lesson activities to help students construct a coherent "story" that makes sense to them. The first step in creating a coherent science content storyline in a lesson is to identify the main learning goal. What *big idea* or crosscutting concept do you want students to learn in this lesson?

A main learning goal IS …

- a big idea (a core science idea or a crosscutting concept) that students are expected to learn and take away from this lesson (or series of lessons).
- a big idea (a core science idea or a crosscutting concept) that shows the relationship among science ideas and can be used to explain multiple phenomena.
- the focus of the lesson (or sometimes a series of lessons) that organizes supporting science ideas, activities, and essential vocabulary terms.
- stated in a complete sentence(s).
- stated by the teacher, a student, a text, or a multimedia program.

The main learning goal should be a core science idea or crosscutting concept that shows the relationship among science ideas and can be used to explain a variety of phenomena. Supporting details or facts aren't appropriate as main learning goals (e.g., "Earth's plates collide"). A main learning goal is an important science concept that warrants at least 40 minutes of lesson time (and possibly more time over a series of lessons). A helpful way to define a main learning goal is to complete the statement, "I want my students to understand and be able to reason using the core science idea that … [*state the learning goal in a complete sentence*]."

The main learning goal should be stated in a complete sentence so it's clear and specific. When you state learning goals as topics or phrases, you aren't challenging yourself to identify exactly what is to be learned and assessed. For example, the phrase "energy flow in energy transfer" sounds good on the surface, but what exactly do you want students to understand about energy flow? Will you focus on energy as it moves through a system or as it flows out of a system as heat? Or will you concentrate on energy transforming from potential energy to kinetic energy? Will you concentrate on the many ways energy is detected in a moving system?

A main learning goal IS NOT …

- a topic or phrase (such as Earth's changing surface, mountain building, energy transfer, or potential energy).
- an activity (such as examining maps for features).
- a question (such as "How does energy change in a system?" or "What landforms are recognizable on Earth's surface?").
- a performance task or objective (such as "Design and conduct an investigation to find out how you can change the amount of energy in a marble" or "Describe the flow of energy through a simple system").
- a supporting detail, definition, or fact (such as "Rocks break apart"; this is a factual statement, not a big idea).
- a misconception—a student idea that isn't scientifically accurate (such as "The Appalachian Mountains are shorter, so they must be younger than the Rocky Mountains").

When planning and teaching science lessons, it's important to keep in mind the complete core science idea you want your students to learn. Therefore, a main learning goal is *not* a topic or phrase (e.g., mountain building or kinetic energy). A topic or phrase lets students know what the lesson is about, generally; however, it doesn't clearly state the central idea that students should come to understand from the lesson. In such an "all about" type of lesson, students might learn a bunch of stuff but feel unsure how that stuff is related and organized as a larger science idea. Such a lesson won't have a coherent science content storyline.

An activity is also not a learning goal. Although you want students to "do science" (e.g., measure the amount of sediment that water carries in a stream table, or measure a ramp's angle of incline), it's important to keep in mind the essential knowledge you want them to take away from those activities. For example, "evaluating an energy-flow diagram of a simple system" isn't considered a main learning goal because it doesn't clearly state a complete science concept students should learn. In contrast, "energy flows through a simple system, and you can detect it in motion, light, sound, or heat" *does* represent a complete science idea that students should learn.

A question isn't a main learning goal either. Although questions may set up the lesson, they aren't explicit statements about the science concept students should learn.

Other science ideas and vocabulary words support the main learning goal, but they should be organized in such a way that they focus on and develop the main learning goal. Therefore, focusing on one main learning goal while you plan and teach a science lesson will help you build a coherent science content storyline.

Examples and Nonexamples of Main Learning Goals

	Main Learning Goal	NOT a Main Learning Goal
Earth's Changing Shape	• Earth's surface has a variety of landforms that change over time. • The collision of Earth's crustal plates causes Earth's surface to build up, forming mountains and other surface features. • *Weathering* is a process that causes rock to fragment, crack, and crumble. As a result of this process, rock is broken down into smaller and smaller pieces.	• What landforms are recognizable on Earth's surface? *(Question)* • Examining maps to identify landforms *(Activity)* • Mountain building *(Topic)* • Rocks break apart. *(Factual statement, not a big idea)*
Energy Transfer	• Energy can move from one object to another when objects collide. • Energy is neither created nor destroyed.	• Where does the energy come from in a moving object? *(Question)* • Constructing energy-flow diagrams *(Activity)* • Potential energy *(Topic)* • Kinetic energy is energy of motion. *(Definition, not a big idea)*

Strategies to Create a Coherent Science Content Storyline

Analysis Guide A:
Identifying One Main Learning Goal

State the main learning goal being analyzed: ____

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Criteria for Main Learning Goal	Yes	No
1. Is the main learning goal stated in a full sentence that represents a science idea (not a topic, phrase, activity, or question) that students could take away with them at the end of a lesson?		
2. Do the students already know the science content reflected in the learning goal? If yes, you need to make the learning goal more challenging.		
3. Is the learning goal an important science idea? a. It is worthy of 40 minutes or more being spent on it. b. It has important connections to other science ideas and can be used to explain a variety of phenomena. c. It is a big idea, a key concept, and not just a supporting fact, example, or detail.		
4. Do students have misconceptions or confusion about this science idea?		
5. Does this learning goal challenge students' thinking and/or misconceptions? If there is evidence that students already understand the learning goal, it isn't meaningful.		
6. Is the learning goal grade-level appropriate and matched to state and/or national standards?		
7. Is the learning goal scientifically accurate?		

Suggest how to improve the main learning goal: ____

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy B:
Set the Purpose with a Focus Question or Goal Statement

The science content storyline in a lesson begins with a focus question or goal statement that directs students' attention to the main learning goal for the lesson. An appropriate focus question or goal statement should be closely matched to the lesson's main learning goal (not just the activities), should be worded in language students can understand at the beginning of the lesson, and should avoid scientific terminology they might learn later in the lesson. The focus question may serve as a way to elicit a variety of student ideas at the beginning of the lesson, as an organizer throughout the lesson, and as a way to assess student understanding at the end of the lesson.

The ideal uses of a focus question or goal statement are to

- elicit students' initial ideas at the beginning of the lesson,
- engage student interest in the science content,
- serve as an organizer throughout the lesson (e.g., "Does this activity contribute any new information about our focus question?"), and
- bring closure to the science content storyline at the end of the lesson (e.g., "Can you summarize what you've learned about our focus question?").

How Is the Focus Question/Goal Statement Related to the Main Learning Goal (Strategy A)?

Focus questions and goal statements are used to help students understand the purpose of the lesson without stating the main learning goal itself. In some subject areas and schools, teachers are encouraged to state the complete main learning goal (or standard) at the beginning of the lesson. In science, however, we want students to construct understandings of the main ideas through the use of scientific practices and reasoning. We want them to investigate scientific questions. The focus question supports this process and also provides a lesson framework that surrounds the development of the main learning goal without giving away the "punch line" at the beginning of the lesson. The main learning goal should guide the selection of the focus question or goal statement, resulting in a close alignment between them.

Examples of Focus Questions and Goal Statements

Earth's Changing Surface	Main learning goal: Earth's outermost layer is made up of tectonic plates. The movement of tectonic plates can lead to a buildup of Earth's surface in some places.			
		1. NOT Closely Linked to the Main Learning Goal	**2. NOT Understandable and Engaging to Students (Uses Scientific Terminology)**	**3. Is Linked to the Learning Goal and Is Understandable and Engaging to Students**
	Focus Question	What are mountains and where do we find them?	How does the collision of tectonic plates lead to mountain formation?	How do mountains form?
	Goal Statement	Today we're going to learn about the structure of Earth's surface.	Today we're going to learn about uplift and the collision of tectonic plates that lead to mountain formation.	Today we're going to learn about the processes that help build mountains.

Energy Transfer	**Main learning goal:** Energy is transformed.			
		1. NOT Closely Linked to the Main Learning Goal	**2. NOT Understandable and Engaging to Students (Uses Scientific Terminology)**	**3. Is Linked to the Learning Goal and Is Understandable and Engaging to Students**
	Focus Question	Where is energy?	How does potential energy transform into kinetic energy?	Where does the energy of a moving object come from?
	Goal Statement	Today we're going to learn about energy.	Today we're going to learn about the relationship between the height of an object off the ground and potential energy, and how that energy transforms into kinetic energy.	Today we'll learn how Mumford got the energy to move down the hill.

Strategies to Create a Coherent Science Content Storyline

Analysis Guides B and I:
Setting the Purpose and Summarizing Key Science Ideas

Criteria for Strategy B: Setting the Purpose	Yes	No
1. Does the focus question or goal statement help students anticipate one main learning goal for the lesson? If yes, write the implied main learning goal here:		
2. Does the focus question or goal statement use everyday language that students will understand at the beginning of the lesson? If no, what words need to be changed?		
3. Is the focus question or goal statement presented in a scientifically accurate way? If no, what is inaccurate?		
4. Would the goal statement be improved if it were turned into a focus question? If yes, provide a suggested focus question here:		

Criteria for Strategy I: Summarizing Key Science Ideas	Yes	No
1. Is there some kind of summary statement or activity in the lesson?		
2. Does the summary focus on conceptual understanding and not just a list of facts or activity procedures?		
3. Do the science ideas in the summary match the main learning goal and the focus question or goal statement?		
4. Is the summary statement/activity scientifically accurate?		
5. Are students engaged in making sense of the summary statement?		
6. Could the summary be improved? Write suggested modifications on the back of this page.		

Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy C:
Select Activities That Are Matched to the Learning Goal

Student activities in science classrooms come in many forms—observing phenomena, constructing models, drawing diagrams, conducting experiments, interpreting graphs, discussing ideas in a small group, completing a worksheet, reading from a textbook, answering questions, carrying out a role-play, and more. Too often, however, science activities are selected for the wrong reasons, such as because they're easy and cheap to do or fun for students. While it's important to consider activities that are manageable, affordable, and engaging to students, these aren't adequate reasons for choosing an activity.

An activity can help develop the science content storyline only if it is closely matched to the main learning goal. So the most important question to ask when selecting activities is this: "Does the activity provide opportunities for students to understand the main learning goal of the lesson?" If an activity doesn't closely match the main learning goal, it shouldn't be used, no matter how cool or fun it is.

Activities that are matched to the main learning goal can help develop the science content storyline by doing one or more of the following:

- Challenging common student misconceptions related to the main learning goal
- Providing observable evidence to support or help develop the main learning goal through student interpretation and reasoning
- Presenting new information about the main learning goal in ways that students can understand
- Guiding students in developing an understanding of the main learning goal
- Providing opportunities for students to practice using and applying new ideas about the main learning goal in a variety of real-world situations
- Providing opportunities for students to synthesize and make connections among ideas that support the main learning goal

Activities that are matched to the learning goal DO NOT …

- include ideas, details, or steps that distract from the main learning goal, or
- reinforce common student misconceptions.

Examples of Activities Closely Matched to the Learning Goal

About Earth's Changing Surface

Learning goal: Moving water changes the surface of Earth through the processes of erosion and deposition.	
Activities NOT CLOSELY MATCHED to the Learning Goal	**Activities CLOSELY MATCHED to the Learning Goal**
Students simulate rain by spraying water on three different Earth materials: sand, soil, and rocks. Next they simulate flowing water by slowly pouring a small amount of water on each of the three Earth materials. Then they write about how sand, soil, and rocks respond differently to rain and flowing water.	Students conduct an investigation of water flowing through a combination of sand, soil, and small rocks in a stream table. They observe what happens to each of these Earth materials when water flows through them over a period of time. During the investigation, students pay close attention to where the sand, soil, and rocks erode and where they are deposited. They record the results by drawing and describing the changes they observe. They label where materials eroded and where those same materials were deposited.

About Energy Transfer

Learning goal: The production of heat, light, sound, or motion indicates that an object has energy.	
Activities NOT CLOSELY MATCHED to Learning Goal	**Activities CLOSELY MATCHED to Learning Goal**
Students construct a device that demonstrates the transfer of energy from a moving object to another object. Then they trace the flow of energy through the system.	Students role-play having a lot of energy and having no energy, and they observe what their classmates are doing. Then students observe several simple systems that move, make sound, and produce light and heat. They become "energy detectives" and record observations that indicate that the system has energy.

Strategies to Create a Coherent Science Content Storyline

Analysis Guide C:
Selecting Activities Matched to the Learning Goal

List the main learning goal: ____

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Part 1: Identify and analyze the science ideas in the activity. Using the table below, first list in the left column each science idea (main and supporting) that is addressed in the activity. Then indicate in the right column how closely each idea matches the main learning goal.

All Science Ideas in the Activity **(Name of Activity)**	The science idea is (*closely, partially, weakly, not*) matched to the main learning goal.
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Part 2: If there are weak or partial matches, suggest ways the activity could be modified to more closely match the main learning goal.

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy D:
Select Content Representations and Models Matched to the Learning Goal and Engage Students in Their Use

Although students need opportunities to conduct investigations and gather evidence to build explanations, they cannot be expected to construct understandings held by the scientific community from firsthand evidence alone. Their understandings of their investigations will grow as they also learn about the core science ideas and crosscutting concepts that scientists have constructed over the history of science. How will you give students access to these science ideas?

There are a variety of ways of doing this. Two of the most common are (1) telling students about it (e.g., lecturing) and (2) having students read about it in a textbook or other source. These traditional approaches can play a role in instruction but aren't adequate to help a diverse group of students understand science concepts that are often complex, abstract, and even counterintuitive. Using content representations, such as analogies, metaphors, diagrams, charts, graphs, concept maps, models, videos, simulations, and role-plays, can help make science ideas more concrete and real for students. Content representations can be especially useful in helping students see how the science content storyline fits together. For example, students can construct diagrams or concept maps to show their understandings of how the ideas they've been studying are connected.

Representations of real-life phenomena are also useful when the phenomena are difficult or impossible for students to observe firsthand in a classroom setting (e.g., earthquakes, tectonic-plate collisions, energy transfer). Representations can help students imagine things they can't see in a classroom setting—things that are too small, too large, too far away, or too abstract; things that no longer exist on Earth; or things that occur too quickly or slowly for students to perceive firsthand.

One type of representation translates scientists' mental, or conceptual, models into artifacts that can be shared with others, including diagrams, animations, or 3-D constructions. These models are especially important in scientific reasoning, and students should be engaged in learning how to construct and represent their own models, as well as how to use others' models. Like scientists, students can *build* mental models to help with reasoning about phenomena and then create representations of these models. For example, students might think first about different directions Earth's plates might move and then draw a diagram with arrows to illustrate their ideas. Students can also deepen their understandings by *using* scientists' models to make sense of phenomena they observe. For example, students might use an energy-flow diagram to track energy transfers and transformations in a system.

Examples of Representations on Earth's Changing Surface

- Relief maps of different locations on Earth
- Stream-table models
- Hard-boiled egg representing Earth's structure (e.g., crust, mantle, and core)

Examples of Representations on Energy Transfer

- Graphs or meters showing the transfer of potential energy to kinetic energy
- Energy-flow diagrams
- A marble and a ramp representing a boy riding a bike down a hill

Sample Analyses of Content Representations

Example 1a. Earth's Changing Surface: Using the Criteria in Selecting Content Representations

Main learning goal: Water reshapes Earth's surface by eroding rock and soil in some places and depositing them in other places.

Content representation: Using a stream table, students record erosion and deposition patterns among different stream slopes. They can experiment with faster- and slower-moving water and make predictions about where erosion and deposition might occur.

Analyzing the Earth's Changing Surface Representation

Is this content representation scientifically accurate? There are many similarities between stream-table models and actual water flow in rivers and streams that make this model scientifically accurate. However, the model's accuracy may depend on its sophistication. For example, are materials used similar to those found in actual streams (e.g., sand, clay, humus, pebbles, and rocks), or does the model represent only one type of material found in streams, such as sand?

Is this content representation likely to make sense to young students? Yes, most students will have had experience with a stream, creek, or river in real life. This model represents a stream on a smaller scale, which allows students to examine erosion within the classroom. However, it's important to help students make the connection between their models and their experiences with real-world streams.

Might the content representation introduce or reinforce misconceptions about erosion? Students might conclude from working with a stream table that erosion is always a fast process. It's important that teachers emphasize the time frame necessary for erosion to occur. In some situations, large storms can cause a large amount of erosion in a short period of time. In normal situations, erosion of materials in streams and rivers occurs over an extended period of time.

Does the content representation distract students from the main learning goal with too many details or new terms? The opportunity to use water and build a stream-table model can be very engaging and messy; however, the opportunity to run simulations of actual processes outweighs the messiness. Careful attention to the design of the stream table (e.g., materials, size, water usage, and capture of the water and soil/sand) and clear cleanup procedures can keep the focus on the main ideas.

Suggestions for improving the content representation: To make clear connections to important science concepts related to erosion and deposition, make sure students have the opportunity to experiment with a broad range of variables, such as the slope of a stream or materials in the substrate.

Example 1b. Earth's Changing Surface: Engaging students in *Using* Content Representations

In addition to presenting students with a content representation, such as the stream-table model, a teacher could ask them to perform the following tasks:

- Suggest ways to modify the stream table to better represent a local waterway by adding a dam or sandbars and lowering or raising the level of the source of water entering the stream.

- Draw the resulting landforms from their stream-table investigations and compare them to pictures of different rivers and streams.
- Analyze data from a local river to compare turbidity, flow of water, and deposition of materials downstream with data gathered from their stream-table models. (Data for local rivers are available online at the US Geological Survey website.)

Example 2a. Energy Transfer: Using the Criteria in *Selecting* Content Representations

Main learning goal: Energy is conserved.

Content representation to be analyzed: The teacher organizes a small group of students for a class role-play. One student will represent energy and will move "through" the students that represent a hand-crank flashlight. The student representing energy has cards that say "motion," "heat," "sound," and "light." As the teacher narrates the role-play and "energy" moves through the flashlight, the student playing the role of energy holds up the appropriate cards to show how energy transfers through the system. The student tosses the cards away from the students in the role-play to demonstrate times when energy transfers out of the system.

Analyzing the Energy-Transfer Role-Play

Is this content representation scientifically accurate? The role-play not only shows energy moving through a simple system but also demonstrates that energy often transfers out of a system. However, the role-play represents energy as a "thing" or some type of matter that moves through the system, and this isn't accurate.

Is the content representation closely matched to the main learning goal of the lesson? The role-play shows how energy changes and moves in a system. It also demonstrates that energy is neither created nor destroyed.

Is this content representation likely to make sense to young students? The role-play engages students in acting out a very abstract idea. This will help students make sense of energy transfer through a system and begin to grasp the idea that energy is conserved.

Might the content representation introduce or reinforce misconceptions about energy? Yes, this role-play introduces or reinforces the common misconception of energy as a "thing" or substance that moves through systems. A student playing the role of energy reinforces this widely held and common misconception. Students are likely to come away visualizing energy as matter or some type of liquid or gas moving through a system. For this reason, teachers are discouraged from using representations that include energy as a "thing" that moves.

Does the content representation distract students from the main idea with too many details or new terms? The representation provides a way for students to visualize energy transfer and energy conservation. It's simple and doesn't include too many details.

Example 2b. Energy Transfer: Engaging Students in *Using* an Energy-Transfer Diagram

In addition to demonstrating how to draw an energy-transfer diagram, the teacher could ask students to perform the following tasks:

- Interpret the diagram and come up with some generalizations: What is the diagram showing about energy as it flows through a system?

- Draw their own energy-transfer diagram with a new, simple system, discuss their diagrams with their teams, and revise them based on advice from their teammates.
- Suggest a way to modify the representation to show how heat leaves the system.
- Discuss this question with their group: How can I show that energy is neither created nor destroyed?

Analysis Guide D:
Selecting and Using Content Representations

Main learning goal: ____

____

Description of content representation: ____

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Part 1: Selecting the Content Representation

Is the Content Representation …	Yes	No
1. Scientifically accurate?		
2. Closely matched to the main learning goal?		
3. Presenting science ideas in ways that are comprehensible to students?		
4. Reinforcing or introducing student misconceptions?		
5. Addressing common student misconceptions?		
6. Distracting students from the main learning goal with too many details or new terms?		

Part 2: Engaging Students in Using the Content Representation

Is the Content Representation Used in a Way That Involves Students In …	Yes	No
1. Modifying or creating the content representation?		
2. Analyzing the meaning of the content representation?		
3. Critiquing the content representation?		

Part 3: Suggestions for Improvement

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy E:
Sequence Key Science Ideas and Activities Appropriately

Sequencing of key science ideas and activities is critical to the development of coherent science content storylines both within and across lessons. Coherent sequencing is also important across units and school years.

Sequencing across Lessons, Units, and Years

Because it takes time for students to develop meaningful understandings of core science ideas and crosscutting concepts, lessons—and even units—need to carefully build on one another. All the lessons in a given unit should address the same overarching question—sometimes called a *driving question* or a *central question*. As the lessons proceed, students should be able to track their evolving understandings related to this overarching question.

For example, a 4th-grade unit about Earth's changing surface might be organized around this central question: "What causes Earth's surface to look different in different places?" To answer this question, students develop an understanding of the core science ideas about Earth's surface being a dynamic system that is always changing, with tectonic processes happening below the surface causing mountains to build up, and weathering and erosion occurring at the surface, shaping the land and wearing it down.

A unit about energy might be organized around the question, "What happens to energy in simple systems?" To answer this question, students must recognize when energy is present, what constitutes an object with more or less energy, where the energy comes from, and where it goes. At the end of each day's lesson, students should be able to reflect on new ideas related to the central question as well as remaining unanswered questions to be investigated.

In a similar way, there should be strong connections across units during the school year and across school years. At the end of the school year, for example, students should be able to describe how all the units they studied fit together. They should also be able to identify and use important crosscutting concepts.

Research shows the value of such a connected curriculum. Allison is a student who struggled academically. During her 5th-grade year, she experienced a science curriculum that had a strong science content storyline across units. At the end of the school year, as she helped her teacher take down the class science bulletin boards, Allison started telling the story of her 5th-grade science learning in an impromptu conversation with her teacher:

> You know, Ms. Ashton, all that stuff we studied in science this year, it all kind of fit together in the end, didn't it? I mean, we learned how plants make food, and then we learned how we use the food plants make in our cells. And then we learned about how food and energy and stuff go in ecosystems. And how the first living things were like one-celled plants, and it's like it all goes back to the plants.

Josh, another student in this class, was watering the classroom plants one day when he remarked, "You know, Ms. Ashton, I used to think that plants just sit there, but they're actually quite busy little things, aren't they?"

Other students in this class were interviewed a year later, at the end of 6th grade, and they were still able to make meaningful connections among ideas about plants making energy-containing food out of non-energy-supplying raw materials (air and water), the chemical reactions taking place in the cells of all living things that release the energy stored in food, the cycling of matter, and the flow of energy in ecosystems. This kind of connected understanding took time to develop and an explicit focus on connecting core ideas. The students weren't taught many of the details that are typically taught about photosynthesis, cellular respiration, and energy transfer. But they developed a strong understanding of some connected core ideas that stuck with them and proved useful to them as ways of thinking about the world. Such understandings grew out of a clear, explicit science content storyline across the school year.

Some important resources can help you plan meaningful sequences of science ideas and concepts across units and school years. The American Association for the Advancement of Science (AAAS) has produced two atlases with Strand Maps that show how core science ideas related to a variety of science ideas (e.g., mountain building, erosion and deposition, energy transfer, gravity) might be sequenced across K–12 grade levels (AAAS, 2001, 2007). Additional information can be found in the National Research Council report *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and in the *Next Generation Science Standards* (NGSS Lead States, 2013).

Before turning to sequencing within lessons, we leave you with this quote from the NRC report (2012), which reminds us that meaningful understandings take time to develop, and that coherence needs to be developed at multiple levels: within lessons, across lessons, across units, and across school years.

> *Research on learning shows that supporting development of this kind of [science] understanding is challenging, but it is aided by explicit instructional support that stresses connections across different activities and learning experiences.… To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months.* (NRC, 2012, pp. 25–26)

Sequencing within Lessons

The order in which various content ideas, terms, and activities are introduced within a lesson should be carefully planned so that the sequence of ideas is clear and the sequence of activities supports the development of the ideas. It's important to first get clear on the main learning goal and supporting ideas to be developed. What is a sequence of ideas that will make sense as a story to your students? Keep in mind that a typical problem in sequencing lessons is the inclusion of too many ideas, which makes it difficult for students to find a clear storyline. Activities should be selected after the main learning goal and key supporting ideas have been selected and the science ideas have been sequenced into a strong storyline. Ask yourself these important questions: Will the activity enhance the development of the ideas and storyline? Which activities will help create a clear and meaningful flow of ideas for students?

There are a variety of ways to sequence science ideas and activities in a lesson. One approach is to begin with a discussion of the focus question, followed with an investigation to gather data about the question. The interpretation of data collected during the activity is then used to help students develop explanations and understandings of a new science idea. In this case, the new ideas and relevant terms are introduced somewhat late in the lesson, arising out of a need to describe what students observe or how they're making sense of the activity.

Another approach is to answer the focus question close to the beginning of the lesson by explaining ideas to students or having them read or watch a video about a new idea. This presentation of new ideas might be followed with a series of activities that allow students the opportunity to use and discuss the new ideas in a variety of real-world contexts. For example, a teacher might introduce some key ideas about how energy transfers from one object to another and then have students use these ideas to explain real-world phenomena, such as a collision between two boys on their bikes.

Although the NRC *Framework* and the NGSS emphasize helping students construct understandings from their investigations of data, there is no one right way to sequence the storyline of a lesson. The most important questions to ask are as follows:

- Is the storyline closely matched to the main learning goal?
- Is the progression of science ideas clearly laid out (i.e., a clear beginning, middle, and end)?
- Are there any gaps or holes in the flow of science ideas?
- Is the storyline cluttered with too many ideas, distracting ideas, or “orphan” ideas (ideas that are mentioned but aren’t central to the storyline)?
- Are ideas scientifically accurate?
- Are activities closely matched and linked to the science ideas in the storyline?
- Will the lesson activities engage students in thinking about the main learning goal and supporting science ideas (versus just doing the activity)?
- Are there markers, such as focus questions, linking statements, summary statements, or highlighted statements, that help tie the science content storyline together?
- Will the storyline be visible and make sense to students?

See the following examples of weak and strong lesson sequencing.

Earth’s Changing Surface: Weak Example of Sequencing

This lesson example is weak because there are too many science ideas and activities, without a clear focus on one main learning goal. This is what we refer to as an “all about” lesson—in this case, “all about volcanoes.” In addition, the ideas in this lesson about processes that build up Earth’s surface aren’t connected to one another in any logical sequence. The lesson starts with a focus on how mountains form, but this idea isn’t addressed in the lesson activities.

Weak Sequence of Earth’s-Surface Science Ideas	Weak Sequence of Earth’s-Surface Activities
Erupting volcanoes are the only way mountains form.	Today we’re going to learn about how mountains form. Can anyone tell me what a volcano is?
There are many different types of volcanoes.	*Activity 1:* Students compare photos of different kinds of volcanoes.
Volcanoes exist all over the world, and some of them exist in patterns.	*Activity 2:* Students look at a map of the world and identify where all the active volcanoes are. They also identify any patterns in their location.

Weak Sequence of Earth's-Surface Science Ideas	Weak Sequence of Earth's-Surface Activities
Volcanoes erupt and release magma—called *lava* on the surface—that hardens over time and changes the landscape.	*Activity 3:* Students watch a video of an erupting volcano and identify where the lava is flowing. They also look at before-and-after pictures of major eruptions.
	Lesson ending: What did you learn today about how mountains form?

Energy Transfer: Weak Example of Sequencing

This lesson example is weak because even though the main learning goal is clear (Energy is transformed; it's neither created nor destroyed), the activities aren't well matched to the learning goal, and too many science ideas are introduced. Students learn about forces, gravity, friction, and energy, but they're confused about what they're supposed to be learning. The many science ideas introduced detract from the main learning goal and the big ideas for the lesson.

Weak Sequence of Energy-Transfer Science Ideas	Weak Sequence of Energy-Transfer Activities
	Today we're going to learn about energy and how it changes.
Friction is a force that opposes motion. Heat is generated because of friction between two surfaces. *Gravity* is a force that pulls objects together. A force can cause motion. *Heat* is the energy that moves between objects of higher temperature to objects of lower temperature. *Energy* is the ability to do work.	After students perform a set of activities (rubbing their hands together to produce heat, dropping a ball, rolling a marble down a ramp, and pushing a toy car), they're asked, "What caused the energy?" Students then create entries in their personal glossaries for the vocabulary terms *friction*, *heat*, *gravity*, *force*, and *energy*.
Gravitation potential energy is the energy of an object due to its position above Earth.	Students revisit the ramp and marble and determine that the higher ramp caused the marble to produce the most energy rolling down the ramp. Students add *gravitational potential energy* to their glossaries.
More motion = more heat = more energy	Students rub their hands together slowly and then quicky to determine that the quicker they rub their hands together, the more heat or energy they feel. Then they read about heat leaving a system because of friction (e.g., stopping a car, eventually stopping a rolling marble) and learn that energy is released into the environment as heat.

Earth's Changing Surface: Strong Example of Sequencing

In this lesson, there is a clear main learning goal stating that Earth's surface has a variety of landforms that are distributed in different patterns. The lesson begins and ends with a focus question that is well matched to this learning goal. Lesson activities engage students in thinking about the focus question. In addition, the lesson begins and ends with clear links to other lessons, developing a storyline across lessons as well as within the lesson.

Strong Sequence of Earth's Changing Surface Science Ideas	Strong Sequence of Earth's Changing Surface Activities
There are many different landforms on Earth.	The teacher elicits student ideas for the first focus question, *Does the surface of Earth look the same everywhere?* and writes students' ideas on the board.
The surface of the United States has a variety of landforms. Specific landforms, such as mountains and river valleys, can be found in many different locations.	The teacher introduces a relief map of the US to students, and they study the map closely. The teacher asks, "Can you add any ideas to the list we started on the board?"
The landforms on Earth's surface aren't the same everywhere. There are patterns in the distribution of landforms on Earth's surface.	The teacher asks, "Do you see any patterns in where landforms occur? Use the map to describe the patterns you see." As student share their ideas, the teacher writes them down.
Landforms on Earth's surface have changed over time and might continue to change in the future.	The teacher asks, "Do you think the surface of Earth changes?" and students give examples. The teacher records examples on the board and probes student ideas.
Earth's surface doesn't look the same everywhere; it's always changing.	*Lesson ending:* The teacher says, "So today we learned that Earth's surface doesn't look the same everywhere, and it's always changing. Tomorrow we'll explore what causes Earth's surface to look the way it does."

Energy Transfer: Strong Example of Sequencing

In this lesson, there is a clear and simple main learning goal: Energy is transformed; it's neither created nor destroyed. Students learn that the moving object they've been investigating got its energy from being above the ground (in a location that's higher than ground level). They learn that this type of *potential energy* can change (or transform) into motion energy (*kinetic energy*).

Strong Sequence of Energy-Transfer Science Ideas	Strong Sequence of Energy-Transfer Activities
Energy isn't created; it must come from somewhere.	*Focus question:* "Where does the energy of a falling object come from?" Students think about and predict where the energy comes from for an object to move down a hill.
Some forms of energy can't be detected the same way kinetic energy is detected. These forms of energy are present because objects are high above the ground or store the energy. This is a type of potential energy that can transform into kinetic energy.	The idea of potential energy is introduced as students read a story about a boy (Mumford) sitting on his bike at the top of a hill.
An object above ground level has potential energy. Potential energy can transform into kinetic energy as the object moves from a higher place toward a lower place. Energy isn't created; it comes from somewhere.	Students understand that the energy to move down a hill or a ramp comes from the potential energy an object has because it's above the ground. They create and use content representations to analyze relative amounts of potential and kinetic energy of a marble as it rolls down a ramp. Students verbally describe their content representations, relating potential energy and kinetic energy. Students transfer the science ideas they've learned about marbles and ramps to the story of a boy (Mumford) on his bike at the top of a hill. They summarize how potential energy and kinetic energy are involved as Mumford coasts down the hill on his bike.

Strategies to Create a Coherent Science Content Storyline

Analysis Guide E:
Sequencing the Science Content Storyline within a Lesson

Part 1: List All the Science Ideas in the Lesson in Sequence (Main Ideas, Supporting Ideas)	Part 3: Suggest a Revised Sequence of Science Ideas in This Lesson

Part 2: Criteria for Sequencing the Science Content Storyline	Yes	No	Comments
a. Is the storyline closely matched to the main learning goal?			
b. Is the progression of science ideas clearly laid out (i.e., a clear beginning, middle, and end)?			
c. Are there any gaps or holes in the flow of science ideas?			
d. Is the storyline cluttered with too many ideas, distracting ideas, or "orphan" ideas (ideas that are mentioned but aren't central to the storyline)?			
e. Are ideas scientifically accurate?			
f. Are activities closely matched and linked to the science ideas in the storyline?			
g. Will the lesson activities engage students in thinking about the main learning goal and supporting science ideas (versus just doing the activity)?			
h. Are there markers, such as focus questions, linking statements, summary statements, or highlighted statements, that help tie the science content storyline together?			
i. Will the storyline be visible and make sense to students?			

Part 3: Make suggestions for revising the sequence. (*Record in right column of chart on previous page.*)

Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy F:
Make Explicit Links between Science Ideas and Activities

Most good stories move smoothly from one paragraph, event, or chapter to the next. Similarly, a science lesson with a strong science content storyline should be a connected thread of content-related activities and talk leading from the focus question or goal statement through a linked flow of events and science ideas to the conclusion or final summary. Activities that students carry out should be explicitly linked to the content storyline so the science ideas are made visible to students before, during, and after completing an activity and get students thinking about the science ideas (not just the procedures). Therefore, each main activity in a lesson should have a setup, a way of focusing students on the science ideas during the activity, and a follow-up with explicit links to the science content storyline.

Using Science Ideas before the Activity

Setup for the activity makes explicit links to science ideas. Many times, teachers get so caught up making sure students understand the procedures for carrying out an activity, they forget to engage them in talking about the *purpose* of the activity as it relates to the main science idea (learning goal) of the lesson. It's important that students have a chance to consider the activity in terms of what science ideas they will learn and how those ideas connect to the developing storyline. In planning to teach, consider how you will set up each activity so it requires students to think or make predictions about the science ideas related to the activity.

Using Science Ideas during the Activity

The activity is designed so that it requires students to make links between the activity and the science ideas. The activity is structured in a way that requires students to think about the science ideas in order to complete the task successfully. Many times, students can successfully finish a task by simply following procedures without thinking about the science ideas embedded within the activity. In the following chart are examples of activities that are structured in ways that do and do not require students to make links between an activity and the science ideas. In planning to teach, design the activity so that students are required to think about science ideas while they're carrying out the activity.

Using Science Ideas after the Activity

Follow-up to the activity focuses on linking the activity with science ideas and the science content storyline. After each activity, students' attention should be focused on the ways in which the activity contributes to the science content storyline. In a follow-up to the activity, students go beyond simply describing their observations and results to thinking about how the activity relates to the science ideas and the focus question of the lesson. The following chart shows examples that help students understand the purpose of an activity as it relates to the science ideas. In planning to teach, leave time after each main activity to engage students in thinking about the ideas related to the activity.

To make sure you are explicitly linking a science idea and an activity, ask yourself the following questions:

- Am I (or the students) stating a science idea (in a complete sentence) and indicating how that idea is related to the activity students will do, are doing, or have done?

  AND/OR

- Can I clearly identify the science idea (in a complete sentence) I expect students to think about before, during, and after an activity? Can *students* identify the science idea?

Examples of Activities That Are Explicitly Linked/Not Linked to Science Ideas

About Earth's Changing Surface

	Setup for the Activity	During the Activity	Follow-Up to the Activity
Activity and Science Ideas ARE NOT EXPLICITLY LINKED	"Let's read the directions for today's science activity." The teacher passes out the worksheet, and the class reads the directions together. Then the teacher summarizes the directions: "So each pair of students is going to get two foam mats and move them in the ways shown in the pictures—slide them side by side, push one over top of the other, push them toward each other, and so forth." *[The focus is on the activity, not the science ideas.]*	The teacher provides pairs of students with two foam mats. Students follow the directions on the worksheet, pushing two foam mats toward each other, sliding them side by side, and pushing one on top of the other. *[The focus is on the activity, not the science ideas.]*	"Let's put away our materials now. Tomorrow we'll talk more about our foam mats and what they're modeling." *[There is no discussion of science ideas related to the activity.]*

	Setup for the Activity	During the Activity	Follow-Up to the Activity
Activity and Science Ideas ARE EXPLICITLY LINKED	"Today's focus question is *How are mountains formed?*" "Take a few minutes and talk about this question with an elbow partner. How do you think mountains might be formed?" "We're about to work with foam mats to represent the plates of Earth's crust. Can you think of any ways that mats might be like or not like Earth's crust?" *[Students are engaged in thinking about science ideas, not just procedures.]*	"Using these mats, work with your partner to come up with ideas about how Earth's flat surface (the clay) could be changed into a mountain." Students work in pairs with the mats and write down their ideas about how mountains might form. Students share their observations and drawings of what happened with the mats. They discuss how pushing and sliding forces changed the shapes and features of the mats. *[Students are engaged in thinking about the science ideas related to their observations.]*	"Let's review our focus question: *How are mountains formed?*" "Now let's read a scientist's description of how the Himalayan Mountains are being built." Students look at a photo of the Himalayas and read about forces pushing two tectonic plates together. The teacher asks, "Does this explanation about tectonic plates match anything you did with your foam mats?" *[The teacher challenges students to make connections between their ideas and scientists' ideas.]*

About Energy Transfer

	Setup for the Activity	During the Activity	Follow-Up to the Activity
Activity and Science Ideas ARE NOT EXPLICITLY LINKED	The teacher gives students a handout with directions for setting up two ramps of varying heights. The teacher tells students where to get materials and what rules to follow as they work in teams to complete the activity. *[The focus is only on the activity, not the science ideas.]*	Students work together to set up two ramps of varying heights. Then they roll a marble down each ramp and observe how far the marble pushes a piece of Styrofoam. Students record their measurements and observations in a data table. *[Students are engaged in the activity and don't have to think about the science ideas.]*	The teacher encourages students to put all their materials away and hand in their work. Then the teacher announces, "Tomorrow we'll read a story about a boy riding a bicycle down a hill. This is similar to your ramps and marble." *[The teacher makes a link to the next lesson and a possible link to the activity, but no science idea is mentioned.]*

	Setup for the Activity	During the Activity	Follow-Up to the Activity
Activity and Science Ideas ARE EXPLICITLY LINKED	Students are asked to predict what would cause a marble rolling down a ramp to go faster or slower. Then the teacher asks students to describe why they think these factors might impact the speed of the marble. *[Students are engaged in thinking about science ideas, not just procedures.]*	Students work with marbles and ramps to test their predictions. Each small group creates an energy-flow diagram showing a method that produced a faster or slower marble. Group members then write a two- or three-sentence caption including the word *energy* to describe why they think one setup resulted in more speed, and the other resulted in less speed. *[Students are engaged in gathering evidence and linking their evidence to science ideas describing the energy of moving objects.]*	Groups examine other groups' diagrams and captions. Each small group discusses the similarities and differences between the various setups and explanations. As a class, students identify similarities and differences and write the best explanation that includes the idea that steeper ramps move the marble higher off the ground, producing greater potential energy that results in greater speed (kinetic energy) for the marble. *[The teacher challenges students to use science ideas about energy to identify relationships between the steepness of a ramp, the height of an object, an object's speed, and energy.]*

Strategies to Create a Coherent Science Content Storyline

Analysis Guide F:
Making Explicit Links between Science Ideas and Activities

Part 1

Activity Description	
Main Learning Goal and/or Focus Question	
Supporting Science Ideas Intended to Be Developed through the Activity Setup, the Activity Itself, and the Activity Follow-Up (*Number Each Idea.*)	

Part 2

Criteria for Explicit Links between Science Ideas and Activity	**Analysis of Explicit Links between Science Ideas and Activity**		
1. Setup for the Activity	**Yes**	**No**	**Your Analysis of Links in the Setup**
a. Are students prompted to think or write about the focus question or goal statement? b. Are explicit links made between science ideas and the activity? c. Does the setup help students understand why they're doing the activity (e.g., what ideas they will learn from it)?			

Criteria for Explicit Links between Science Ideas and Activity	Analysis of Explicit Links between Science Ideas and Activity		
2. During the Activity	**Yes**	**No**	**Your Analysis of Links during the Activity**
a. Do students think about science ideas during the activity? *(Consider: Do students use ideas, or are they focused on procedures?)* b. Do students know they're expected to connect science ideas with what they're doing in the activity? (*Consider: Does the activity or the teacher help students connect science ideas to what they're doing?*)			
3. Follow-Up to the Activity	**Yes**	**No**	**Your Analysis of Links in the Follow-Up**
a. Are science ideas explicitly linked to the activity in the follow-up? If so, indicate what the teacher does or what the students do to link ideas with the activity. b. Are *students* involved in making links between the science ideas and the activity?			

Part 3: Are the linked science ideas well matched to the main learning goal and/or focus question of the lesson? Explain your reasoning.

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy G:
Link Science Ideas to Other Science Ideas

Although each lesson should focus on one main learning goal, students will develop deeper understandings of the learning goal if they comprehend how it's built from and connected to other supporting science ideas and concepts. Any science ideas introduced in a lesson should be clearly and explicitly linked to the main learning goal and should help develop (and not distract from) the science content storyline. In addition, there should be a strong science content storyline *across* lessons. The links between science ideas introduced in one lesson and those in the next lesson should be made visible to students. High-quality links between science ideas have the following features:

- Two (or more) science ideas are being linked. You should be able to state each idea being linked in a complete sentence.
- The link is between ideas, not ideas to activities or activities to activities.
- The ideas being linked are closely matched to the main learning goal.
- The link is clear, explicit, and comprehensible to students.
- The link is scientifically accurate.
- The teacher and/or the students can make the link between ideas.

Following are the different kinds of links that will help build a strong science content storyline within and across lessons.

Links to Previous and Next Lessons

Each lesson begins with links to science ideas and concepts (not just to activities!) developed in previous lessons. This can be done by referring back to the science content storyline being developed and/or to focus questions addressed in previous lessons. Similarly, the lesson might end with some hint of how the science-content ideas in today's lesson might be further developed in the next or future lessons.

Examples of Linking Ideas across Lessons

Beginning of lesson on Earth's changing surface: "Our unit central question is *Why isn't all of Earth's surface flat? What causes the surface to look different in different places?* Last time, we learned that Earth's surface has a lot of different landforms, and landforms change. We also learned that the landforms we see have patterns. Today we'll continue our exploration of why Earth's surface looks the way it does. So how do you think mountains form?"

End of lesson: "Today we learned that there are slow-moving plates on Earth's surface. These plates have something to do with how mountains form. Tomorrow we'll explore how these plates move and how these movements might make mountains."

Links between Supporting Ideas and the Main Learning Goal

Supporting ideas and specialized terminology should be clearly linked to the main learning goal. The teacher sometimes does this linking. For example, the teacher might use a visual representation, such as a diagram or a concept map, to clarify the relationships among ideas.

However, science-learning research suggests that students will develop deeper understandings if they're challenged to make the connections themselves, with careful probing and guidance from the teacher. For example, students could construct simple concept maps to explain the relationships among key science ideas. Then the teacher could link this activity to the main learning goal and use students' efforts to assess and address missing links in their understandings.

Teaching and learning research also suggests that students will find specialized terminology more comprehensible if they first experience a phenomenon and come to understand in everyday words the basic ideas related to it. Then later they can attach scientific terminology to an idea or experience they already hold, and the teacher can link the idea or experience to the main learning goal. For example, students first observe changes they can make in foam mats by pushing and sliding them against each other. The pushing and sliding usually result in new features or formations in the mats. Students can be encouraged to think about how similar pushing and sliding of Earth materials could impact the formation of mountains in the real world. After students experience this process, they learn that scientists call it *uplift* (building up). Although it's sometimes helpful to front-load, or preteach, vocabulary for English language learners, in *science* teaching, it's more meaningful for students to experience the concept first and then learn the specialized vocabulary.

Links to the Focus Question/Goal Statement

The focus question or goal statement can be used as a conceptual organizer throughout the lesson and in the synthesize/summarize activity at the end of the lesson. Each idea that is addressed can be linked to the focus question. For example, consider a lesson where students are exploring the question, *Where does the energy of a moving object come from?* The teacher elicits student ideas about the answer to this question as students consider a young boy riding his bike down a hill. Students predict where they think the boy might get the energy to coast (move) down the hill. Then they read a story about the boy and his bike and learn about how the boy had potential energy at the top of the hill. They also learn how potential energy can be transformed into motion energy or *kinetic energy*. Afterward, the teacher returns to the focus question, and students describe verbally and in writing where the boy got the energy to move down the hill on his bike.

In another example, consider a lesson where students are exploring the question, *What evidence is there to support the idea that tectonic plates collide and build mountain ranges?* In the lesson, students are given three different maps with data to support the idea that plates collide and form mountains. One map shows plate boundaries, one map shows the location of physical features, and one map shows active volcanoes and earthquakes around the world. Students can overlay the data to see patterns in the locations of mountain ranges, active volcanoes, and earthquakes that occur at plate boundaries. The teacher links these data back to the lesson focus question, *What evidence is there to support the idea that tectonic plates collide and build mountain ranges*?

To make sure you're making a link between one science idea and another, ask yourself these questions:

- Am I making a statement that connects two (or more) science ideas? Can I clearly identify the ideas being connected in complete sentences (not just topics)?

  AND/OR

- Am I engaging students in finding and making connections between two (or more) science ideas? Can I clearly identify in complete sentences (not just topics) the ideas I expect students to connect? Can *students themselves* identify the ideas?

Strategies to Create a Coherent Science Content Storyline

Analysis Guide G:
Linking Science Ideas to Other Science Ideas

Main learning goal and/or focus question: ____

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Part 1: Where do you see links made between one science idea and another science idea? Write time codes in the gray header row of the chart below. Then analyze the links by answering the five questions in the chart.

Is the link between science ideas a high-quality link?

Criteria for Linking Science Ideas to Other Science Ideas	Link 1 Time:	Link 2 Time:	Link 3 Time:	Link 4 Time:
1. Are two (or more) complete science ideas being linked together (or is the link only at a topic or activity level)?				
2. Are the science ideas being linked well matched to the main learning goal?				
3. Is the link clear and comprehensible to students (or is it unclear or too vague)?				
4. Is the link scientifically accurate?				
5. Is the link likely to help students develop a coherent science content storyline?				

Part 2: How can the weak links be strengthened?

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Part 3: What additional links could be added? Where should they be added?

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy H:
Highlight Key Science Ideas and Focus Question Throughout

The science content storyline is easier to follow if the main learning goal, supporting science ideas, and flow of events are highlighted at key points during the lesson.

Highlighting actions include

- referring back to the focus question throughout the lesson;
- writing key science ideas on the board, a transparency, or chart paper;
- telling students, “This is a key science idea”;
- having students write key science ideas in their notebooks;
- providing visual representations that highlight key science ideas;
- revisiting key science ideas multiple times in a lesson; and
- summarizing at key transition points in the lesson.

The teacher can highlight key science ideas in a variety of ways, such as asking about them repeatedly through review questions, having students say or repeat important ideas, pointing out that a particular science idea is very important, and guiding students to underline or highlight key sentences on a worksheet.

Students can also take the lead in highlighting key science ideas. They might be asked to identify the key ideas from a reading or respond to a question about the most important science ideas discussed in the lesson thus far. For example, the teacher might stop at key transition points in the lesson to highlight the ideas developed so far:

- “What does this activity tell us about our focus question: *How do mountains form?* Let’s write down the main things we’ve learned so far.”
- “What have we learned so far about what happens to energy when objects collide?”

Strategies to Create a Coherent Science Content Storyline

Analysis Guide H:
Highlighting Key Science Ideas and Focus Question

Main learning goal or focus question: ____

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Part 1: Where do you see examples of highlighting key science ideas? Write video time codes in the gray header row of the chart below. Then analyze the quality of the highlighting by answering the five questions in the chart.

Is this highlight of high quality?

Criteria for Highlighting Key Science Ideas	Highlight A Time:	Highlight B Time:	Highlight C Time:
1. Does the teacher mark a key science idea (not just a topic or activity) as important?			
2. Is the highlighted science idea(s) matched to the main learning goal?			
3. Are students likely to notice and understand that this idea is important?			
4. Is the highlighted idea scientifically accurate?			
5. Is the highlighting done in a way that is likely to help students construct a coherent science content storyline?			

Part 2: How can these highlights be strengthened?

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Part 3: What additional highlights could be added? Where?

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Strategies to Create a Coherent Science Content Storyline

STeLLA Strategy I:
Summarize Key Science Ideas

The science content storyline needs to be tied together at the end of a lesson. A summary statement is one way to make connections between the science ideas and activities addressed in the lesson and highlight how they support the main learning goal of the lesson.

A summary statement typically occurs near the end of the lesson. The teacher can state it as a strategy for returning students' attention to the focus question or goal statement and for clarifying the intended learning goals. Student Thinking Lens strategy 7 focuses on engaging students in the synthesizing and summarizing process. This is usually more supportive of student learning, but if time is short, a teacher summary is better than no summary at all.

Challenging learning goals are rarely neatly addressed and wrapped up in one lesson. Sometimes a lesson summary may be a statement of where we are today and what we still have to learn before we can answer our focus question.

In developing summarizing statements and activities, consider the following questions:

1. Does the summary focus on conceptual understandings and not just a list of facts or activities?
2. Do the science ideas in the summary match the main learning goal and the focus question or goal statement? By thinking about the focus question, main learning goal, and summary together, teachers make sure the science content storyline is tied together for students by the end of each lesson.
3. Is the summary statement/activity scientifically accurate?
4. Are students engaged in making sense of the summary statement?

Examples of Summarizing Key Science Ideas

About Earth's Changing Surface

T:	Today we explored how mountains are formed. There is one key idea from this lesson that we'll build on in the next couple of lessons. That key idea is "Mountains can get built up when the plates of Earth's crust crash (push) into each other." *[The teacher writes this idea on the board.]* What evidence do we have from today's lesson to support this key idea?
Jenna:	We saw from the map that where two plates come together, there are usually mountains.
T:	Excellent. Other evidence?
Tony:	And what we did with the foam mats. When we pushed them together, you could make a mountain.
T:	And what did the foam mats represent?
Tony:	The plates of Earth's crust.

About Energy Transfer

T:	Today we explored what happens when two objects collide—in particular, what happens to energy when a moving object runs into an object that isn't moving. Who can summarize their ideas from the lesson?
Emily:	The object that was moving fast (Mumford on his bicycle) slowed down and then stopped.
T:	Why do you think that happened?
Emily:	The energy of the moving object didn't go away; it got transferred to the object that wasn't moving.
T:	How do you know energy was transferred?
Emily:	The other object (Leroy on his bicycle) started moving.
T:	We also learned that energy can change "costumes." What does that mean?
Benito:	It means that energy can change what it looks like. Like it can change from moving energy to the sound of the crash or the heat from skidding across the sidewalk.
T:	Energy may look, sound, or feel different when it changes, but it's still energy. When there is a collision or any other interaction between objects, we can detect these changes and represent them in a diagram. You represented these changes in your energy-flow diagrams.

(*Note:* The analysis guide for strategy I appears earlier in this document. See Analysis Guides B and I on page 49.)

Summary of STeLLA Science Content Storyline Lens Strategies

<table>
<tr><th></th><th colspan="2">Strategy</th><th>Purpose</th></tr>
<tr><td rowspan="6">Develop the Science Content Storyline during Planning</td><td colspan="2">Identify one main learning goal.</td><td>To identify the complete science concept you want students to learn (for teacher)</td></tr>
<tr><td colspan="2">Set the purpose with a focus question or goal statement.</td><td>To provide a focus for the lesson that keeps attention on the main learning goal (for students)</td></tr>
<tr><td colspan="2">Select activities that are matched to the learning goal.</td><td>To select activities that help students deepen their understandings of the main learning goal</td></tr>
<tr><td colspan="2">Select content representations and models matched to the learning goal and engage students in their use.</td><td>To select content representations and models that help students deepen their understandings of the main learning goal</td></tr>
<tr><td colspan="2">Sequence key science ideas and activities appropriately.</td><td>To develop a science content storyline that will make sense to students</td></tr>
<tr><td colspan="2">Summarize key science ideas.</td><td>To plan how the storyline will be tied together</td></tr>
<tr><th></th><th>Strategy</th><th>When in the Lesson</th><th>Purpose</th></tr>
<tr><td rowspan="5">Develop the Science Content Storyline during Teaching

NOTE: Planning is a critical step in being prepared to revisit, highlight, and link.</td><td>Set the purpose with a focus question or goal statement.</td><td>At the beginning and highlight throughout</td><td>To focus students' attention on the purpose of the lesson</td></tr>
<tr><td>Make explicit links between science ideas and activities.</td><td>• Before each activity
• During each activity
• After each activity</td><td>To make the science content storyline visible to students

To engage students in thinking about the science ideas related to the activities</td></tr>
<tr><td>Link science ideas to other science ideas.</td><td>• Beginning: Link to ideas from previous lessons
• During lesson: As appropriate
• End: Link ideas developed during the lesson and in previous lessons; foreshadow next lesson</td><td>To make the storyline visible to students

To engage students in thinking about the connections among science ideas</td></tr>
<tr><td>Highlight key science ideas and focus question throughout.</td><td>Multiple times during the lesson</td><td>To make the main learning goal and supporting ideas more visible to students</td></tr>
<tr><td>Summarize key science ideas.</td><td>End of the lesson</td><td>To tie the storyline together</td></tr>
</table>

References

American Association for the Advancement of Science (AAAS). (2001, 2007). *Atlas of science literacy* (Vols. 1–2). Washington, DC: AAAS Project 2061.

Krajcik, J., & Reiser, B. J. (2004). *IQWST: Investigating and questioning our world through science and technology*. Evanston, IL: Northwestern University.

National Research Council (NRC). (2008). *Ready, set, science! Putting research to work in K–8 science classrooms*. Washington, DC: National Academies Press.

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press.

Roth, K. J., Druker, S. L., Garnier, H. E., Lemmens, M., Chen, C., Kawanaka, T., … Gallimore, R. (2006). *Teaching science in five countries: Results from the TIMSS 1999 video study*. Washington, DC: National Center for Education Statistics. Retrieved from http://nces.ed.gov/timss.