A SCIENCE EDUCATION CURRICULUM STUDY

Strategies for Effective Science Teaching:
The Student Thinking and Science Content Storyline Lenses
Grade K-3

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

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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.

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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 of plants being producers.
- **Evidence:** At video segment 16:54, the teacher comes over and asks Miriam to explain her diagram of matter in a food web. Miriam says that the plants take in matter from the soil and pass it along to the mouse.

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.*

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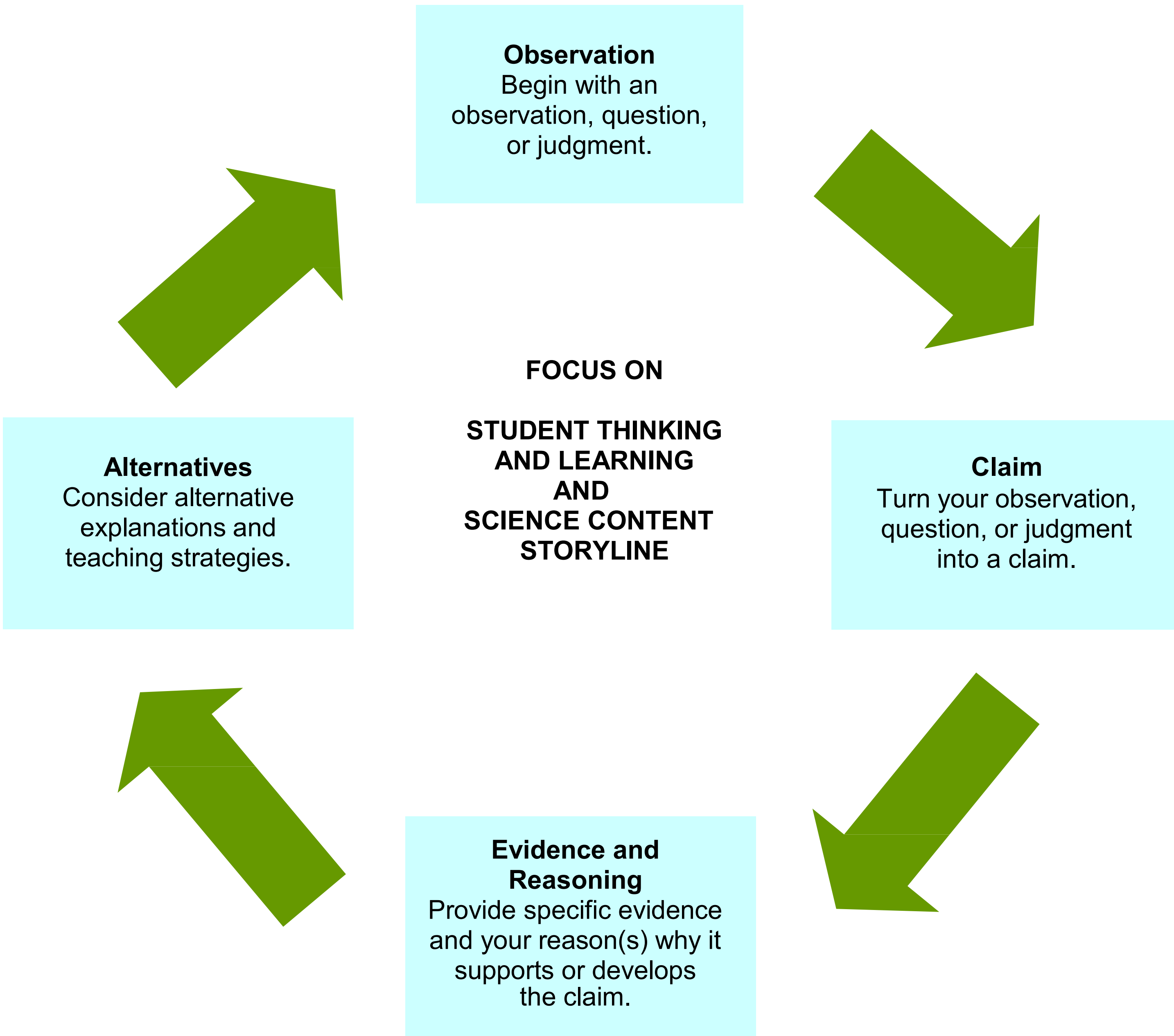
Learning from Lesson Analysis



Analysis of Student Thinking

Lesson Analysis Stage	Example
Observation Begin with an observation, question, or judgment.	• Do students really understand the purpose of this activity?
Claim Turn your observation, question, or judgment into a specific claim.	• Students don't understand that this activity is intended to demonstrate that trait variations in cottonwood-tree seeds explain why some seeds survive and others don't.
Evidence and Reasoning Provide specific evidence and reason(s) why it supports or develops the claim.	• Students are asked what they learned from the activity with the fan and cottonwood-tree seeds. In video segment 29:30, Constanza states that heavier seeds don't travel as far as lighter seeds. When the teacher probes for more information, Constanza has nothing to add. At segment 32:33, Manuel echoes basically the same idea ("lighter ones go further"). These students aren't using any language about traits or talking about what this means for the seeds' survival. They observe and identify patterns (strategy 4), but they don't use observations or science ideas to construct explanations (strategy 5).
Alternatives Consider alternative explanations and teaching strategies.	• This would be a good time to ask a challenge question, such as *Can you use the idea of traits to explain what we saw happen in this activity?* This question might have supported Constanza and Manuel in moving forward in their thinking.

Analysis of Science Content Storyline

Lesson Analysis Stage	Example
Observation Begin with an observation, question, or judgment.	• Did this activity match the main learning goal?
Claim Turn your observation, question, or judgment into a specific claim.	• I think the focus on drawing loud-wave and soft-wave diagrams distracted students from the learning goal.
Evidence and Reasoning Provide specific evidence and reason(s) why it supports or develops the claim.	• The learning goal is "Vibrating objects produce sound." The teacher focused on this goal when she asked whether all of the students' soundmakers caused things to vibrate. After many students called out, "Yes!" the teacher showed the class how to draw wave diagrams (video segment 21:20). However, as students discussed these drawings (segments 28:32–32:00), no one ever mentioned vibrations. All they talked about were loud sounds making big waves and soft sounds making small waves. So I thought the coherence of the content storyline was lost at this point.
Alternatives Consider alternative explanations or teaching strategies.	• I think the teacher should have spent more time probing and challenging students' ideas about the question, *Do all soundmakers cause things to vibrate?* This would have provided valuable information to help the teacher determine whether students really understood the main learning goal.

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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 (trait variation, forces),
- a student activity ("Students are making bubble maps comparing trait variations in plants and animals."),
- 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 uneven heating on Earth (a topic), we aren't clarifying the difference between what students think about water in their world and what scientists have learned about how water changes and is conserved in the water cycle.

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.

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Examples of Science Ideas about Earth's Changing Surface

a. A canyon is one kind of landform. (*Fact*)
b. When water runs downhill, it moves some of the soil and rocks on Earth's surface. (*Accurate statement and observable pattern*)
c. Earth's surface is constantly changing. (*Concept*)
d. The movement of Earth's tectonic plates caused by heat from the interior explains many of the changes on Earth's surface. (*Theory*)

Examples of Science Ideas about Variations in Plants and Animals

a. Cottonwood trees produce seeds that the wind carries away. (*Fact*)
b. Some seeds can travel farther than others. (*Description of observed pattern*)
c. *Claim:* Cottonwood-tree seeds that are lighter in weight have a better chance of surviving and growing. *Evidence:* Our evidence is that we used the fan to test how far light and heavier cottonwood-tree seeds would fly, and we discovered that lighter seeds traveled farther. *Reasoning:* We read in a science book that seeds have a better chance of surviving if they're farther away from the parent tree. This makes sense because these seeds will be able to get more light and water. So that's why we think the lighter cottonwood seeds have a trait that will give them a better chance of surviving and producing young. (*Explanation*)
d. Variation in traits affects which plants or animals of the same kind survive long enough to produce young. (*Concept*)

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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 forces or variation in traits, how are students already thinking about events in their daily lives when they encounter different traits in plants or observe the effect of forces pushing or pulling objects? What are their personal theories about how plants of the same kind show variation in traits or why objects move or don't move? What knowledge and experience do they draw on to predict what will happen if multiple forces act on an 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 seeds won't grow in the dark. Observing seeds germinating in the dark 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 photosynthesis is?" most students will have nothing to contribute. In contrast, many students will be able to respond to the question, "How do you think a plant gets its food?" 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 Plants and Animals

- What do you think plants and animals need to live?
- How are plants and animals different from one another?
- Do you think plants need food? How do they get their food?
- How does an environment help meet an animal's needs?

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 get into the middle of the street?
- In what ways do rivers cause changes on Earth's surface?
- 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 grow taller or become smaller?
- Can mountains grow so tall they reach outer space? Why or why not?

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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?

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- 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 Plants and Animals

T: What do you think plants need to live and grow? *(Elicit)*

S: I think plants need sunlight.

T: Why do you think plants need sunlight? *(Probe)*

S: Sunlight helps them be healthy and grow strong.

T: What does it mean for a plant to be healthy and strong? *(Probe)*

S: It means that the plant is green and can stand up straight.

T: Tell me about how you think sunlight helps a plant do that. *(Probe)*

S: Without sunlight, plants can't make food.

T: So sunlight helps plants make food? Tell me more about that *(Probe)*

S: Plants use sunlight, water, and air to make food.

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 dirt at the bottom of the stream.

T: Tell me more about that. (*Probe*)

S: The water is going really fast, so it pushes some of the small rocks and dirt along with it.

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 Plants and Animals	**About Earth's Changing Surface**
T: What is the word for the place an animal lives? S: *Home*. T: Is there a different word for that? S: *Shelter*? T: We were talking about a more scientific word for it yesterday. S: Oh! *Environment*.	T: The Grand Canyon is getting deeper and deeper. What causes that? S: Earthquakes. T: You think earthquakes? But what did we do yesterday with the trays? S: Ummm … T: What's at the bottom of the Grand Canyon? S: Dirt and rocks? T: What's flowing through the Grand Canyon? S: The Colorado River. T: Is the Colorado River causing the Grand Canyon to get deeper? S. Yes!

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?

Example of Content-Specific Questions That Challenge Student Thinking

About Plants and Animals

T: What do plants need to live and grow? (*Elicit*)

S: They need food.

T: What do you mean by food? (*Probe*)

S: Plants make food to live and grow.

T: How do they make the food? (*Challenge*)

S: From water and air and sunlight.

T: So is water food for plants. (*Probe*)

S: No. Plants use water to *make* food.

T: Let's go back. You said that plants make food from water, air, and sunlight. Is that right? (*Probe*)

S: Yes.

T: What parts of the plant help it get each of those things? (*Challenge*)

S: The water comes in through the roots. The air comes in through little holes in the leaves. And the sunlight comes in through the leaves too.

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?

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- 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.)

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Examples of Analyzing and Interpreting Data and Observations

About Weather

- Students collect weather data using observations and weather instruments (such as a thermometer) and look for weather patterns over time.
- Students organize weather data (e.g., the temperature and rainfall conditions outside) and record this information on a weather chart or calendar.
- Students record weather data on bar graphs to help them analyze weather patterns (e.g., number of sunny day, number of cloudy days).
- Students interpret patterns in the weather data to help them think about the short-term forecast and the long-term climates of a specific location.

About Forces

- Students collect data on the distance a toy car travels over different surfaces (carpet, tile, and rough sandpaper). Then they record their data on a class data table and look for patterns in the distances the toy car traveled.
- Students closely examine the three different surfaces (carpet, tile and sandpaper) and connect their observations to the data on how far a toy car traveled over each surface.

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 the Sun rises in the east, why tides rise and fall in a predictable pattern, and why we are similar—but not identical—to our parents. 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. Thomas is a kindergarten student in a hands-on science class in which students collected data on the weather, making careful observations and measurements over the course of a month. Thomas and his classmates gave detailed descriptions of the weather outside and created beautiful graphs showing sunny days and cloudy days. Thomas was a careful observer. But at the end of the unit, he was frustrated: "It was fun at first to collect weather data. But I always knew it's usually sunny outside, and sometimes we have clouds."

All that measuring and observing didn't lead Thomas to any new understandings about weather. The entire activity led him to a description of *what* weather is without any new understandings of *why* it's important to recognize weather patterns in different places.

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.

[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.

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.

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.

Example of Constructing Explanations and Engaging in Scientific Argument

About Weather

Context: Students examine picture graphs showing the weather data they collected over the past month for their area and for another location with very different weather. Their task is to analyze the patterns they observe in each graph (strategy 4), identify similarities and differences between the graphs, and use patterns and evidence from the graphs to develop an explanation that answers the question, *Is weather the same everywhere?* (strategy 5).

T: What can we say about the weather patterns we observed on our graphs?

S1: I think our place is sunnier than Place B.

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T: What's your evidence?

S1: Our place has more sunny days than cloudy days.

T: Can you provide more details about that and give us some data from the graphs? *(Strategy 4)*

S1: There were 18 sunny days this month and only five cloudy days.

T: Who can add to that evidence?

S2: I think that our weather is mostly sunny during November, because 18 is more than five, so that means it's sunny. Place B isn't sunny at all.

T: What do you mean by "Place B isn't sunny at all"? Do you have some evidence?

S2: Almost all their days are cloudy. *(Strategy 4)*

T: So can you use this evidence to answer our focus question: *Is weather the same everywhere?* What is your claim—your answer to this question—and your evidence? Please answer in a complete sentence. *(Transition to strategy 5)*

S3: I think that weather isn't the same everywhere. My evidence is what we found out about the weather differences in these two places.

T: Tell me your reasoning. Can you connect your claim and evidence to any of the science ideas we've been studying? Give me a complete explanation that includes your claim, your evidence, and your reasoning. *(Strategy 5)*

S3: OK. My claim is that weather isn't the same everywhere. My evidence is that we have more sunny days than Place B. My reasoning is that there must be some difference between Pomona and Place B that causes us to have more sunny days than Place B. Maybe Place B is at a higher altitude, because we learned that it's cooler at higher altitudes. Maybe it's cooler because it's cloudy. *(Strategy 5, Explanation)*

T: What do others think about this explanation?

S4: I agree with the idea that maybe Place B is at a higher altitude, because I sometimes see clouds covering up Mount Baldy when it's sunny down here. *(Strategy 5, Argument)*

T: Any other ideas?

S5: I like the idea about altitude, but Place B could be cloudy for another reason. *(Strategy 5, Argument)*

T: Do you have another reason to suggest?

S5: Maybe it's more polluted in Place B. Pollution causes smog. *(Strategy 5, Argument)*

S6: But it's really polluted here, and we have lots of sunny days. *(Strategy 5, Argument)*

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T: Who has a different claim or reasoning?

S2: I agree with S3 that weather isn't the same everywhere, and I agree with his evidence. But I have a different reason.

T: What's your reasoning?

S2: We went to San Francisco, and it was, like, cloudy and foggy every morning, and I think it was because it was right next to the ocean. *(Strategy 5, Argument)*

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 a trait?"). 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

Example of Using and Applying New Ideas

About Variation in Traits

- After studying about how size variations among the wind-blown seeds of cottonwood trees might impact their survival when they land in different environments, students consider whether the concepts of traits, variation, survival, and the environment apply to animals as well as plants. The teacher reads a story about mice—some with tan fur, some with white fur, and some with black fur. The mice live in a shrubby mountain environment. The mountain is a volcano that erupts, killing off the vegetation and covering the ground with lava that hardens into a dark-colored surface. Students are challenged to use their knowledge about trait variations, survival, and the environment to predict what will happen to the mice when they return to the mountain. The teacher asks students to consider these questions:
  - How will changes in the environment affect the mice's survival?
  - Does fur color make a difference in the mice's survival?
  - How might the mice's survival impact the color of baby mice the following year?

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 illustrates how water can shape Earth's surface. Or students might create a concept map that organizes key science ideas about traits and trait variation. Making a concept map and presenting it to the class could be the focus of an entire lesson. Such an activity involves students in actively considering how all the ideas they studied fit together.

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 Variations in Plants and Animals

Example 1:

- In a 1st-grade lesson, students investigate how the wind might carry various sizes of cottonwood seeds different distances. They find that lighter seeds traveled farther, flying over a parking lot and a pond and eventually landing in a plowed field. Heavier seeds fell to the ground sooner, landing on the parking lot or in the pond. After clarifying these results, students are asked to build a story about what helped some cottonwood-tree seeds survive as the wind carried them over the three different environments, and why other seeds didn't survive or travel as far.

- One student begins the story with a sentence that others add to until the story is complete. Students are encouraged to use at least one of the following science words in their sentences:
  - Traits
  - Variation
  - Survive/survival
  - Environment

Example 2:

- At the end of a 1st-grade unit on traits and variation, students consider how trait variations might impact the survival of different individuals in populations of plants or animals. Students are given laminated index cards, each containing one of the following vocabulary words: *traits, variation, survival, environment*. Each word card has a magnet on the back so that students can place the words on the board and rearrange them. The teacher challenges students to think of a sentence using most or all of these words to tell people outside of class why some cottonwood-tree seeds survive and others don't. The sentence starter is *We learned that cottonwood-tree seeds _________.* After some think time, the teacher asks several students to come to the board and share their sentences, arranging the word cards as they speak. Then the teacher challenges the rest of the class to agree, disagree, or add onto each student's sentence.

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

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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>

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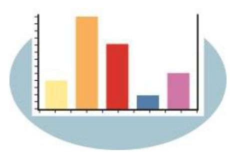
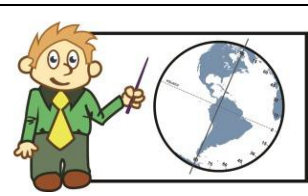
Examples of Ways to Engage Students in Communicating Scientifically

The Communicating in Scientific Ways chart on the following pages 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 …

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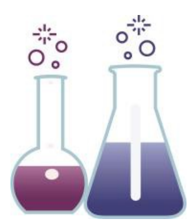
What a Scientist Does	Symbol	What a Scientist Says
7. Listen to others' ideas and ask clarifying questions.		Are you saying that …? What do you mean when you say …? What is your evidence? Can you say more about …?
8. Agree or disagree with others' ideas.		I agree with _______ because … I disagree with _______ 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.

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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., "A tuning fork vibrates back and forth quickly," or "Plants can take in air through tiny holes in their leaves"). 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 "sound and vibrations" sounds good on the surface, but what exactly do you want students to understand about sound and vibrations? Will you focus on what causes an object to vibrate and the sound it produces? Is it enough for students to know that all soundmakers vibrate? Or do you also want them to understand that sound can make objects vibrate?

A main learning goal IS NOT …

- a topic or phrase (such as sound or vibrations).
- an activity (such as producing sound from soundmakers or playing with a computer simulation).
- a question (such as “How does sound from a vibrating object get to my ear?”).
- a performance task or objective (such as “Design a soundmaker and explain how you hear its sound”).
- a supporting detail, definition, or fact (such as “Big vibrations produce loud sounds”).
- a misconception—a student idea that isn’t scientifically accurate.

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., “sound” or “plants and animals”). 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., “Observe and explain vibrations from soundmakers,” or “Observe and explain plant growth in different conditions”), it’s important to keep in mind the essential knowledge you want them to take away from those activities. For example, “We made sounds with cluckers!” isn’t considered a main learning goal because there is no science idea for students to learn. In contrast, “Plants make their own food using sunlight, air, and water” *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
Sound	• To produce a sound we can hear, an object must vibrate. • Vibrating air can make other objects vibrate. • Louder sounds cause bigger vibrations than quieter sounds.	• Sound *(Topic)* • Reasoning about the sounds two different soundmakers produce *(Activity)* • Why are some sounds louder than others? *(Question)* • Sound waves and vibrations *(Not a complete sentence)* • A vibrating rubber band can make a sound. *(Factual statement, not a big idea)*

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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

<table>
<tr><td rowspan="4">Earth’s Changing Surface</td><td colspan="4">Main learning goal: Water can change the land over time.</td></tr>
<tr><th></th><th>1. NOT Closely Linked to the Main Learning Goal</th><th>2. NOT Understandable and Engaging to Students (Uses Scientific Terminology)</th><th>3. Is Linked to the Learning Goal and Is Understandable and Engaging to Students</th></tr>
<tr><td>Focus Question</td><td>Why do we have floods?</td><td>How do weathering and erosion lead to canyon formation?</td><td>How do canyons form?</td></tr>
<tr><td>Goal Statement</td><td>We’re going to learn about floods and land.</td><td>We’re going to learn about how weathering and erosion change the topography of the land.</td><td>Today, we’re going to learn about how canyons form.</td></tr>
</table>

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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.		

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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.

Example of Activities Closely Matched to the Learning Goal

About Earth's Changing Surface

Main learning goal: Water can change the land over time.	
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 the sand, soil, and rocks respond differently to rain and flowing water.	Students use a stream-table model to study how rivers and rain can change Earth's surface. They observe what happens to earth materials when water flows over them throughout a period of time. Students pay close attention to where the sand, soil, and rocks erode and where they're deposited. Then they draw and describe the changes they observed in the model.

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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, fossil formation, 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 consider the different forces acting on a soccer ball as it moves across a field and then draw diagrams with arrows to represent their ideas. Students can also deepen their understandings by *using* scientists' models to make sense of phenomena they observe.

Examples of Content Representations about Matter

- A model using Legos to represent the particles that make up matter, with single Lego bricks representing atoms, and bricks linked together representing molecules
- A role-play in which students act like water molecules to show how adding or taking away heat changes their motion and causes freezing or melting.
- A diagram in which students contrast changes in matter by drawing their Lego molecules before, during, and after a physical change and a chemical change

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Sample Analysis of a Content Representation

Main learning goal: Adding heat can change something from a solid to a liquid, because adding heat causes the molecules that make up matter to move faster.

Content representation: Matter is made up of atoms. Individual Lego bricks are used to represent atoms, and the correct number of Lego bricks connected together represents molecules. To model a water molecule (H_2O), for example, two white bricks (hydrogen atoms) and one red brick (oxygen atom) are linked together. To illustrate a solid, the Lego-brick water molecules are packed tightly into a box, and students wiggle the box to envision how the particles move, or vibrate, in place. To illustrate how heat causes the molecules to move faster and break away from their rigid structure, students transfer the same Lego molecules to a plastic bag (about the same size as the box) and observe how the particles move around each other rather than vibrating in place.

Analyzing the Lego Particle-Model Representation

Is the Lego particle-model representation scientifically accurate? The Lego bricks represent atoms and molecules that are too small for students to see. This model can be used to represent the changes to molecular motion when heat is added or taken away. The model accurately shows that at higher temperatures, water molecules can move around each other rather than remaining in a rigid structure. The model also accurately shows that the molecules remain intact with three atoms (no chemical changes) as they undergo a change in state from solid to liquid. It's important that students understand two inaccuracies of this model: (1) The Legos are much, much larger than the molecules they represent, and (2) heat wouldn't be added by having students shake or manipulate the molecules in a box or plastic bag. Other inaccuracies of the model aren't important for 2nd graders to understand. For example, not represented in the model is the concept that an attraction between different water molecules creates weak hydrogen bonds that hold these molecules together in both the solid and liquid states.

Is the model closely matched to the main learning goal of the lesson? The Lego particle model is closely matched to the lesson's main learning goal because students can see that the movement of water molecules changes when heat is added.

Is this model likely to make sense to young students? During this lesson series, students first observe that solids have a rigid shape and liquids change shape depending on their container. In the Lego particle model, students are challenged to imagine what is happening at a molecular level. While this is a challenging concept for young students, the Legos help them see that the "molecules" in the box retain the rectangular shape of the box, but in the plastic bag, they change position in relation to one another. At this age (2nd grade), students may have difficulty conceptualizing that molecules in a solid state are constantly in motion, vibrating in a rigid structure. This runs counter to their experience with solid materials that don't seem to move at all. However, by contrasting this vibrating motion with the more fluid motion of molecules in a liquid state, they will be able to visualize the difference between the solid and liquid states.

Might the model introduce or reinforce misconceptions about the particulate nature of matter? This model may introduce several misconceptions. The most significant is that molecules in a solid or liquid state have physical boundaries of some kind (like the box or plastic bag in the model, for example) rather than attractive forces binding them to one another. A second misconception that may be introduced is that heat is an outside force acting on molecules—such as students' hands manipulating either the box or the bag of molecules—rather than energy that is part of the molecular system and can be transferred into and out of the system as particles bump each other.

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Another obvious misconception is the relative size and position of the atoms in a molecule. In this model, students use Lego bricks of similar sizes (2" x 2" or 2" x 4" bricks) to represent all atoms in a molecule, and they position the bricks any way they connect. Chemists generally use more consistent rules to represent both the size and position of atoms in a molecule.

Does the model distract students from the main learning goal with too many details or new terms? The model introduces terms that are typically introduced in later grades, such as *atoms* and *molecules*. In earlier grades, students often use the term *particles* rather than *atoms* and *molecules*. The NGSS Disciplinary Core Ideas for this grade level simply require students to know that “a great variety of objects can be built up from a small set of pieces.” But the NGSS also calls for introducing the idea that heating or cooling can cause chemical changes. If we use the term *particles* or *pieces* to think about chemical change, how do we explain that you can start with one kind of particle and end up with another kind of particle? These tiny pieces of matter don’t magically change into new matter (as in the Rumpelstiltskin story about changing straw into gold). Instead, they’re made up of atoms that can rearrange to form new kinds of pieces (molecules). So distinguishing between atoms and molecules isn’t intended to confuse or distract students but to provide clarity when talking about chemical changes.

Suggestions for improving the model: Rather than having students shake or manipulate the molecules in the box and plastic bag, use a mechanical “stirrer.” This device resembles a hot plate and could be modulated, like turning up the heat on a hot plate to show more heat/motion and turning down the heat to show less heat/motion.

Engaging Students in Using the Lego Particle-Model Representation

Students analyze the Lego particle model using an analogy map to link elements of the model to elements of the real world. Some of the boxes on the analogy map are already filled in to give students an example of how to complete each column.

My Lego Model—Analogy Map

Part of the Model	Is/Are Like …	Part of the Real World	Because …
One Lego brick		An atom	The Lego brick is one small piece, and an atom is one small piece of something.
		A molecule	
Two white Lego bricks and one red Lego brick stuck together			
The Lego bricks in the cardboard box			The molecules in a solid can’t move very much, just like the Legos in the box.
		Liquid water	
The Lego bricks jiggling or vibrating in place			The molecules in a solid vibrate in place too.
The Lego bricks moving around more freely			

This analogy map could be improved by adding a column asking students to consider which part of the model is *not* like the real world and why. For example, a Lego brick is not like the real world because it’s large enough to see and doesn’t move on its own based on its temperature.

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Strategies to Create a Coherent Science Content Storyline

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 5th-grade unit about the water cycle might be organized around the central questions, *How does water change in the world around us? Will Earth ever run out of water?* To answer these questions, students develop understandings of core science ideas about changes in matter during evaporation and condensation and the relationship of these processes to the gain and loss of heat. A unit about food webs in a 5th- or 6th-grade classroom might address the driving question, *What would happen to life on Earth if there were no plants?* Addressing this question would involve investigations of the role of plants as producers, the flow of energy from the Sun to producers to consumers, and the cycling of matter in food webs. 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., atoms and molecules, cell functions, gravity, energy in living systems) 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 water molecules behave in the solid, liquid, and gaseous states and then have students use those ideas to explain real-world phenomena, such as "foggy" bathroom mirrors, morning dew on the grass, or wet towels drying on a clothesline.

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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.

Matter: Weak Example of Sequencing

This lesson example is weak because there are too many science ideas, without a clear focus on one main learning goal. The lesson is based on one element of an NGSS disciplinary core idea, but so much information is packed into the lesson that students will have a difficult time learning anything significant.

Weak Sequence of Science Ideas	Weak Sequence of Activities
Different kinds of matter exist.	Students use a definition of *matter* to help them identify examples of matter in the classroom.
Matter can be either solid or liquid.	After students identify several solid objects in the room as matter, they're encouraged to consider that matter can be either liquid or solid. Then they resume identifying examples of matter in the classroom, including liquid forms.
Matter can be either solid or liquid depending on temperature.	*Activity 1:* Students look at photos of a variety of substances. These substances demonstrate that many types of solid matter can change to a liquid state depending on their temperature (e.g., rock/lava, penny/liquid copper, crayon/melted crayon, butter/melted butter). Students rank the items according to the amount of heat they think would be necessary to make an item melt.

Weak Sequence of Science Ideas	Weak Sequence of Activities
Matter can be classified by its observable properties.	*Activity 2:* Using melting point as an identifiable property of matter, students describe other properties of matter related to the photos (e.g., hardness, color, shininess, malleability or the ability to bend, the ability to conduct electricity).
	Lesson ending: Turn to a partner and discuss this question: *What did you learn about matter today?*

Matter: Strong Example of Sequencing

In this lesson, there is a clear main learning goal that helps students develop an explanation for *why* adding heat (heating) or taking away heat (cooling) causes matter to melt or freeze, rather than just observing that temperature differences lead to melting and heating. The lesson builds on earlier lessons that provided students with concrete examples of melting and freezing. The lesson begins and ends with a focus question that is well matched to the main learning goal, and the activities engage students in thinking about this 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 Science Ideas	Strong Sequence of Activities
	Yesterday, we observed matter melting and freezing or becoming solid again.
	The teacher introduces the focus question, *What does heat do that causes matter to change from a solid to a liquid or a liquid to a solid*?
All matter is made up of small pieces.	Students are asked to predict what would happen if they could shrink so small that they could see the smallest particle inside a drop of water. The teacher states that all matter is made up of tiny pieces called *atoms* and *molecules*.
In a solid, molecules vibrate in place. When heat is added to a substance, the molecules move faster. When enough heat is added to a solid, the molecules move faster, break away from their rigid structure, and move around freely as liquid molecules. Cooling a liquid causes the molecules to slow down and change back into a rigid structure.	Students create a Lego model of water particles arranged in a box to represent a solid. They create a second model of the same Lego pieces in a plastic bag to show how the particles are chemically the same but are able to move differently as a liquid. They consider what happens to the molecules when heat is added to a solid or taken away from a liquid.

Strong Sequence of Science Ideas	Strong Sequence of Activities
	Students consider their Lego particle model and use an analogy map to show how the model represents the heating and cooling of matter.
	Students revisit the lesson focus question, *What does heat do that causes matter to change from a solid to a liquid or a liquid to a solid*? Students share their ideas for answering the question; then the teacher highlights key science ideas from the lesson. The teacher links to previous and upcoming lessons: "In lesson 1, you observed many ways that matter can change. Today, we focused our attention on melting and freezing. Tomorrow, we'll consider some of the other changes we observed, like baking, burning, and fizzing.

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.*)

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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.

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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 Forces

	Setup for the Activity	**During the Activity**	**Follow-Up to the Activity**
Activity and Science Ideas ARE NOT EXPLICITLY LINKED	"Yesterday, we defined a *force* as a push or pull. Today, we'll define *gravity*." *[The focus is on the activity, not the science ideas or the key idea of forces.]*	Students drop objects of different shapes, sizes, and masses and collect data on the amount of time it takes each object to fall. *[The focus is on data collection, not on using the data to explain the constant pull of gravity or to connect gravity to the key idea of forces.]*	The teacher asks a few students to share their conclusions. After students clean up from the activity, the teacher states, "Today, we learned about gravity. Tomorrow, we'll learn about another force called *friction*." *[Links topics but not complete-sentence ideas.]*
Activity and Science Ideas ARE EXPLICITLY LINKED	The teacher introduces the focus question, *What causes a moving object to slow down and eventually stop?* Then the teacher elicits students' initial ideas for answering the question. *[Students are engaged in thinking about science ideas, not just procedures.]*	Students use a ramp model to observe the distances a toy car travels over different surfaces. The car travels farther over smooth surfaces and a shorter distance over rough surfaces. Then the teacher introduces a "hand-strip" model. As the car rolls down the ramp and over the hand strip, the hands push back against the car's motion. After the investigation, the teacher asks students to use the words *push*, *pull*, and *force* to explain why	The teacher introduces a new term—*friction*—to describe the force students observed in their investigation. Then students read a short essay describing various examples of friction in the real world. They use these science ideas to answer the focus question, *What causes a moving object to slow down and eventually stop?* *[Students use the term* friction *and ideas about tiny bumps an object encounters on surfaces*

	Setup for the Activity	During the Activity	Follow-Up to the Activity
Activity and Science Ideas ARE EXPLICITLY LINKED		the car slowed down and eventually stopped. *[Students are engaged in thinking about explanations and science ideas related to their observations.]*	*that push against the object's motion to explain why moving objects slow down and eventually stop.]*

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.

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 the properties of matter: Our unit central questions are *What is matter made of? How can matter change?* Yesterday, we observed some ways matter can change, and we created a chart to keep track of our observations. Today, we'll continue exploring changes in matter by focusing on the changes we tracked that we said were reversible, like the liquid water and the ice.

End of lesson: Today, we learned that adding heat can cause matter to melt, like the ice that melted when we added heat. We also learned that taking away heat can cause matter to become solid, like when liquid water turns to ice. Tomorrow, we'll continue thinking about what happens when heat is added to or taken away from substances and why changes in heat can cause melting and freezing.

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 how pushes and pulls cause an object to start moving or stop moving. They're encouraged to visualize how objects slow down and eventually stop because the tiny bumps on surfaces push against each other.

After these experiences, students are introduced to the word *friction*. At this point, the word has some meaning—students have an experience to connect to the word. Teaching friction before the experience will simply be a word to memorize that has little meaning. 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 in which students are exploring the focus question, *What makes an object slow down and eventually stop?* The teacher elicits student ideas and finds out that many students think objects stop moving because the force that started the motion runs out.

Next, students investigate moving objects that slow down and stop at different distances on different surfaces. They find out that tiny bumps on the surfaces push in the opposite direction of an object's motion. Then the teacher links these new ideas back to the focus question: "So do these observations give us any new ideas for answering our focus question, *What makes an object slow down and eventually stop?*"

In another example, consider a lesson where students are exploring the question, *Why can water exist in three forms—liquid, solid, or gas?* In the lesson, students watch a computer activity that simulates how the motion of water molecules changes when water gains and loses heat energy. The teacher then challenges students to describe the connections between heat energy and molecular motion. She then links these ideas back to the focus question: "So do these observations of molecular motion give us any new ideas about our focus question, *Why can water exist in three forms—liquid, solid, or gas?*"

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?

Analysis Guide G:
Linking Science Ideas to Other Science Ideas

Main learning goal and/or focus question: ____

____

____

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 have we learned so far about how plants are like or not like animals?"
- "What ideas do we have so far about why you can hear your classmate whispering to you, but the principal can't hear the sound in her office down the hall?"
- "What do we know so far about what heat has to do with melting and freezing?"

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Strategies to Create a Coherent Science Content Storyline

Analysis Guide H:
Highlighting Key Science Ideas and Focus Question

Main learning goal or focus question: ____

____

____

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?

____

____

____

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 Variation in Traits

T:	What is a big idea you learned from today's lesson? *(Strategy 7)*
Emily:	That black mice survive better in the lava-covered field than white mice do.
T:	Can you use the words we've been studying to describe the big idea from this activity?
Emily:	Mice have different traits. Some of the mice have black fur, some have white fur, and some have tan fur.
T:	Can anyone add on to this idea about different traits?
Arturo:	Even though they're all mice, some have variations in the fur-color trait that help them survive better in the lava environment.

T:	Good! That's a big idea. There are trait variations that affect which organisms survive better in their environment. Can anyone add on to this idea?
Shanda:	The mice that survive can have babies.
T:	OK, all of these are key ideas from our lesson. Today, we learned about what happens when an organism's environment changes. Not just what happens to mice, but to any organism. Organisms that live in the environment have different trait variations that help some of them survive better. Those that survive can go on to produce offspring, or babies. (*Strategy I)*

(*Note:* The analysis guide for strategy I appears earlier in this document. See Analysis Guides B and I on page 45.)

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>

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