GREAT MINDS® SCIENCE

Implementation Guide

A Guide for Teachers

Great Minds® Science

Implementation Guide

Contents

Introduction

The Grade 4 California Edition Implementation Guide is a resource for teachers that further explains the philosophy of Great Minds® Science and the learning design behind specific curriculum components. It also provides additional resources to help make instruction more efficient and effective.

Foundations

Great Minds Science is a new standards-based curriculum from the creators of *Eureka Math*™ and *Wit & Wisdom*™. Grade 4 is the first completed grade of what will become a full Kindergarten through Grade 8 science curriculum. Great Minds believes that every child is capable of greatness, and Great Minds Science seeks to inspire students to wonder about the world and also empower them to make sense of it.

This product consists of four modules in which students actively **engage** in building a **coherent** understanding of scientific **knowledge** that prepares them for success in Grade 5 science and beyond.

- **Knowledge:** Throughout each module, students engage in all three dimensions of the California Science Standards—core ideas, science and engineering practices, and crosscutting concepts. These dimensions are integrated into the curriculum to build a deep understanding of scientific concepts.
- **Coherence:** Each module weaves a story that gives students an opportunity to make sense of compelling phenomena. Lessons build upon one another to help students increase their understanding of the anchor phenomenon and allow them to draw on prior learning. Coherence extends across modules, grades, and even disciplines.
- **Engagement:** Students actively engage in asking questions about phenomena, exploring those questions, analyzing information, and applying new knowledge to solve real-world problems in engineering challenges or to investigate the natural world in science challenges. Differentiation allows all students to engage with rigorous content.

Product Components

Teacher Edition (print or digital)

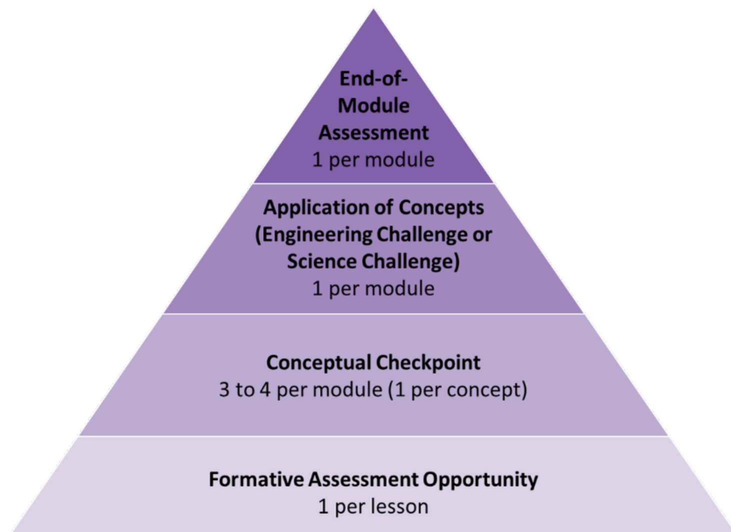
Module Outline

The Teacher Edition begins with a Module Overview that contains a narrative introduction, a module map, standards alignment, a spotlight on three-dimensional integration, terminology, safety considerations, and professional resources for teachers.

Each module contains approximately 25 lessons. The module is organized into three or four concepts that help students make sense of an anchor phenomenon. Each concept contains lesson sets that develop key conceptual understandings.

Throughout the module, four types of authentic assessments give students opportunities to make sense of phenomena and express their knowledge. The assessment opportunities are described below and summarized in the figure.

- Formative Assessment Opportunities provide teachers with information to modify instruction (one per lesson; includes evaluation guidance).
- Conceptual Checkpoints assess mastery of skills identified in each concept's standard(s) (one per concept; includes evaluation guidance).
- Application of Concepts (through Engineering Challenges and Science Challenges) allow students to apply their conceptual knowledge to solve a real-world problem (one per module; includes rubric).
- A summative End-of-Module Assessment gives students the opportunity to demonstrate the knowledge and skills they have acquired throughout the module (one per module; includes rubric).



At the end of each module's Teacher Edition, appendices provide teacher support before and during instruction.

- Appendix A: Teacher Resources—A set of lesson-specific resources to aid instruction, such as full-size photographs, investigation procedure sheets, materials preparation, and supplemental information
- Appendix B: Module Storyline—A more detailed version of the Module Map in the Module Overview that summarizes the progression of concepts within the module
- Appendix C: Module Glossary—Grade-level appropriate descriptions for new terms introduced in the module with their locations within the module
- Appendix D: California Phenomena and Applications—A list of additional and alternate phenomena, resources, or applications specific to the state of California
- Appendix E: Domain-Specific Words, General Academic Words, and Spanish Cognates—A list of important words used in the module and their Spanish cognates to support English language development

Lesson Set Overview

Lesson sets consist of 45-minute lessons grouped by specific phenomena. This structure provides lesson-level pacing suggestions allowing flexibility for students to wonder about and explore the world around them and analyze their findings to arrive at conceptual understandings. All lesson sets have a Prepare section, which includes the following information:

- Introduction—a brief narrative to introduce the lesson set and its three-dimensional integration
- Phenomenon Question—a question that guides learning throughout the lesson set
- Learning Goals—stated learning outcomes for each lesson (to guide teachers, not to post for students)
- Standards Addressed—a summary of the focus performance expectation(s), science and engineering practices, disciplinary core ideas, and crosscutting concepts addressed by the lesson set
- Materials—a list of materials needed for each lesson, including any necessary preparation (optional materials and substitutions are listed where applicable)

Each 45-minute lesson is organized into these sections:

- Launch—the lesson opening
- Learn—the heart of the lesson, during which students develop new knowledge
- Land—the lesson closing
- Optional Homework—suggestions for applying and extending science learning in students' homes and communities

Additionally, each lesson contains embedded instructional supports (e.g., formative assessment opportunities, supports for English language development, safety notes) and sidebar notes with additional information for teachers (e.g., support for diverse learners, extensions, interdisciplinary connections, links between grade levels, spotlights on aspects of three-dimensional learning or environmental principles).

Science Logbook (print)

The Science Logbook is a consumable student resource. This logbook allows students to record evidence, document their learning, and record Conceptual Checkpoint responses. Each module's logbook begins with a Module Question Log for students to record phenomenon-based questions as they explore the anchor phenomenon. In most lessons, students use their logbooks as they complete scientific tasks to develop models or record observations, predictions, data analysis, explanations, claims, and other information.

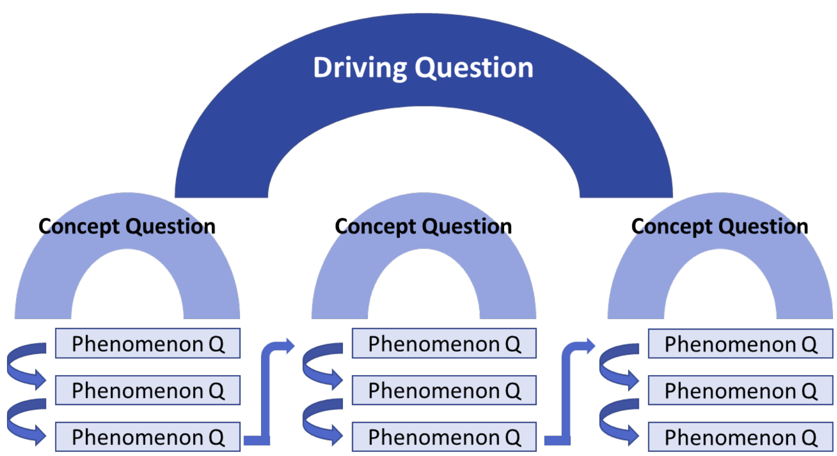
Materials Kits (available from an external supplier)

Materials kits are available from an external supplier. These specially designed kits contain the supplies needed to implement each module. Because school inventories and budgets vary widely, the following purchasing options are available: individual supplies, four individual module kits, a safety kit, or a complete Grade 4 kit that includes all four module kits and a safety kit.

Learning Design

All modules and lessons are expertly crafted by Great Minds teacher–writers and include multiple resources for teachers to help all students achieve greatness.

- **Organizational tools:** As a class, students organize their learning throughout each module with a common set of foundational tools.
  - Driving question board—a chart that drives learning from concept to concept by organizing phenomenon-based student questions and any new questions that arise through investigation
  - Anchor model—a model to explain the anchor phenomenon that students develop and subsequently modify throughout the module as new learning emerges
  - Anchor chart—a chart distilling key scientific understandings that grows as knowledge develops
- **Hands-on experiences:** Lessons offer carefully crafted hands-on experiences that allow students to practice problem solving, collaborate with peers, and build standards-based knowledge.
- **Informational texts:** Authentic, content-rich texts present information about phenomena, scientific concepts, and the history of science.
- **Technology:** Lessons integrate technology when its use supports student conceptual understanding.
- **Vocabulary:** Lessons introduce vocabulary in the context of hands-on investigations to help students make sense of phenomena.
- **Questions:** Throughout each module, three types of overarching questions drive student understanding and coherence. The Module Driving Question motivates student learning throughout the module. Students formulate possible answers to this question through rich discussions, with the understanding that some scientific questions may never be fully answered. Each concept is framed with a Concept Question that builds coherence and understanding of the Module Driving Question. Phenomenon Questions highlight the purpose of lesson sets and tie learning together across lessons. The teacher can provide the lesson set's Phenomenon Question or facilitate student discussion to arrive at a similar question. Building knowledge of one Phenomenon Question leads students to ask questions related to the next Phenomenon Question.



- **Discussions:** Scientific phenomena and investigations have been carefully selected to generate student questions and answers and encourage student-driven learning. Class discussions provide opportunities for students to synthesize and solidify their understanding. Sample discussions (teacher questions and student responses) in every lesson show teachers what a discussion might sound like in the classroom. These samples are an educative component—rather than a script—for teachers as they facilitate learning.

- **Interdisciplinary connections:** Lessons provide opportunities for students to practice English language arts, mathematics, and other cross-disciplinary skills.
- **Educative information for teachers:** Modules provide multiple resources for teachers to deepen their knowledge of science content, pedagogy, and the progression of student learning.

Scope and Sequence

CA NGSS Checklist for Great Minds Science

This checklist provides an at-a-glance view of the performance expectations included in each module as foci of instruction and assessment.

CA NGSS		Module 1	Module 2	Module 3	Module 4
4-PS3	1		X		
	2		X		
	3		X		
	4		X		
4-PS4	1			X	
	2				X
	3				X
4-LS1	1			X	
	2			X	
4-ESS1	1	X			
4-ESS2	1	X			
	2	X			
4-ESS3	1	X			
	2	X			
3–5-ETS1	1		X		
	2	X			X
	3				X

Great Minds Science Grade 4 Curriculum Map

Module 1 The Changing Earth (25 days)	Rock Layers 4-ESS1-1	Weathering and Erosion 4-ESS2-1	Engineering Challenge 4-ESS3-2 3–5-ETS1-2	Patterns in Features and Processes 4-ESS1-1 4-ESS2-2	Human Interactions with Earth 4-ESS3-1	Assessment 4-ESS1-1 4-ESS2-1 4-ESS2-2 4-ESS3-1 4-ESS3-2
Module 2 Energy (26 days)	Energy and Its Classification 4-PS3-2	Energy Transfer 4-PS3-1 4-PS3-3	Energy Transformation 4-PS3-2 4-PS3-4	Engineering Challenge 4-PS3-4 3–5-ETS1-1	Assessment 4-PS3-1 4-PS3-2 4-PS3-3 4-PS3-4	
Module 3 Sensing the Environment (31 days)	Receptors 4-LS1-1 4-LS1-2	Sensing Waves 4-PS4-1	Science Challenge 4-LS1-2	Response 4-LS1-1 4-LS1-2	Assessment 4-LS1-1 4-LS1-2 4-PS4-1	Research Project 4-LS1-1
Module 4 Light: Sight and Communication (27 days)	Sight 4-PS4-2	Properties of Objects 4-PS4-2	Communication 4-PS4-3	Engineering Challenge 4-PS4-2 3–5-ETS1-2 3–5-ETS1-3	Assessment 4-PS4-2 4-PS4-3	

(purple)	Module Name	(green)	Life Science
(blue)	Earth Science	(yellow)	Physical Science
(orange)	Engineering or Science Challenge	(gray)	Assessment

Research in Action

Great Minds Science helps teachers put research-based best practices into action.

Research Says	Students Need	Great Minds Science Responds
A scientifically literate individual "can ask, find, or determine answers to questions derived from curiosity about everyday experiences;" "describe, explain, and predict natural phenomena;" and "read with understanding articles about science in the popular press" (NRC 1996, 22). "Scientists expect to hear skepticism and challenging questions in response to their ideas. Students can adopt such scientific discourse and use it to propose ideas or explanations, to support ideas with evidence, to ask	Students need to be free to follow their curiosity to better understand the world around them. Students need to know how to participate in scientific discourse, ask challenging questions with clarity and precise language, and respond to criticism. Students need to make claims, support their claims with evidence, elaborate on their ideas, and challenge the claims of others.	Great Minds believes that student curiosity should inspire learning. Modules are driven by compelling, carefully chosen, knowledge-rich phenomena that lead to questions about the world. Students create a driving question board that is updated as they find answers to their existing questions or when new questions arise. The curriculum also provides many opportunities for students to engage in scientific discourse. In each lesson, students make observations, develop claims, and defend their claims with evidence. Science challenges and engineering

Research Says	Students Need	Great Minds Science Responds
challenging questions, and to agree/disagree with their classmates' ideas" (BSCS 2015). "Explicitly teaching students about scientific practices and communication will help them better understand the nature of science and also will help them improve the clarity, precision, and elaboration of their ideas" (BSCS 2015).		challenges allow students to work with peers to answer questions or solve problems and present their findings to the class. A Socratic Seminar at the end of each module gives students an opportunity to synthesize their learning, discuss their ideas, and present evidence to support or refute claims.
"[M]isconceptions about the processes of science tend to occur when the processes become ends in themselves, divorced from core concepts of science. For students to learn how to 'do' science, they need to understand the roles of observation, imagination, and reasoning" (Allen 2006, 7).	Students need hands-on experiences that require the practical application of scientific processes. Students need time to observe, imagine, and reason.	With Great Minds Science, students are introduced to new concepts through engaging activities that allow them to first observe and wonder, and then discover and deeply understand phenomena. Students are given opportunities to apply scientific processes in new contexts through science challenges or engineering challenges.
"As the *Framework* states, 'knowledge and practice must be intertwined in designing learning experiences in K–12 science education.' Engaging solely in the practices without including disciplinary core ideas and crosscutting concepts is insufficient because each of these concepts is required to make sense of phenomena" (NSTA 2018). Some educators do not think that current science curricula incorporate the standards deeply or effectively enough. Part of this problem stems from the way standards have historically been written without consideration of connections across topics and grade levels (Allen 2006).	Students need learning experiences that allow them to see connections between scientific ideas, concepts, and practices. Students need learning experiences that are in a context to help them make sense of phenomena and the world. Students need a coherent approach to studying science with clear connections among concepts and across grades.	Great Minds Science is committed to presenting science content deeply, connecting learning within and between grade levels with carefully chosen phenomena woven together, often introduced with stories and the history of science. The curriculum leverages three-dimensional learning and assessment, and these opportunities are highlighted for teachers at the beginning of each lesson set and in notes within lessons. Through this three-dimensional approach, students begin to see connections among scientific ideas, concepts, and practices as they apply their knowledge to understand phenomena and the world.

Research Says	Students Need	Great Minds Science Responds
“Many elementary school teachers, the proverbial jacks-of-all-trades, face a trio of issues when it comes to teaching science: they don’t like science, they don’t feel confident in their knowledge of science, and they don’t know how to teach science effectively” (Allen 2006, 1). Science is one of the first topics elementary teachers cut during the school day because of the need to focus on subjects such as language arts and mathematics (Allen 2006).	Students need dedicated time to study science with teachers who present it effectively. Students need opportunities to practice language arts, math, and other cross-disciplinary skills in a scientific context.	Great Minds Science supports teachers with lesson notes that provide relevant background knowledge and suggested questions to guide student discussions. Core texts are an important component of most modules, allowing teachers to present relatable content and inspiring student learning through compelling and rich stories. Additionally, interdisciplinary connections within lessons highlight opportunities for students to practice grade-appropriate language arts, math, and other cross-disciplinary skills.
“Assessment must be aligned with— a. what is of value, i.e., the problem-solving model of instruction: concept application, inquiry, and process skills. b. the curricular objective and instructional mode. c. the purpose for which it was intended: grading, diagnosis, student and/or parent feedback, or program evaluation” (NSTA 2002).	Students need meaningful and contextual assessments that allow them to apply scientific concepts to different phenomena. Students need assessments that are purposeful, whether diagnostic, formative, or summative.	Great Minds Science offers several types of assessment within each module. Formative Assessment Opportunities are found in each lesson and provide guidance to teachers as they evaluate student progress through the lesson set. Conceptual Checkpoints periodically gauge student understanding of concepts important to move forward in the module. Science challenges and engineering challenges allow students to apply learning in both familiar and unfamiliar contexts. End-of-Module Assessments are divided into three components: first, students participate in a Socratic Seminar to discuss and synthesize module learning; next, a summative individual assessment gives students an opportunity to demonstrate mastery of knowledge and skills acquired throughout the module; and finally, students self-evaluate their learning against module performance expectations.

Getting Started

Safety

Great Minds Science believes that the safety and well-being of students are of utmost importance in all classrooms. In the science classroom, investigations frequently include demonstrations, experiments, engineering tasks, and other activities that involve unique safety concerns not encountered in other classroom settings. These investigations require careful planning and attention to safety protocols.

All educators, including teachers, administrators, and classroom aids must be proactive in creating a safe science classroom. They must act responsibly and prudently to help safeguard students, and they must serve as role models for safety at all times. With the cooperation of parents, educators can help ensure a safer classroom environment while affording students the opportunity to engage in high-quality science learning experiences.

At the outset of each school year, teachers should stress general science safety procedures with students. Teachers are encouraged to have students and parents sign a science safety contract that outlines rules and procedures to ensure a safe classroom experience. A safety quiz is also recommended to assess comprehension of these rules and procedures. Teachers may use the sample contract and quiz provided in Appendix A: Teacher Resources or create their own.

Teachers should revisit the safety rules and procedures frequently during the year. It is strongly recommended that teachers design and hang a safety poster in the classroom. This enables students to refer to it at any time, especially when teachers are explaining safety expectations before a science investigation.

Teachers should exclude any science investigation they believe cannot be performed safely due to inadequate safety engineering controls (fire extinguishers, ventilation systems, eyewash stations, etc.) or protective equipment (safety goggles, gloves, and aprons). All adults present in the classroom are responsible for knowing the location of safety engineering controls, protective equipment, and first aid supplies, and should receive appropriate training related to their use. If a particular safety measure is not available, teachers may elect to modify an investigation if doing so would reduce safety risk while maintaining the integrity of the investigation.

For every science investigation, the teacher must thoroughly explain all relevant safety expectations, precautions, and procedures before students access any materials or equipment. Teachers should monitor student actions and behaviors and immediately address any concerns that arise. Students who disregard safety rules and procedures should be stopped from participating in the investigation until they have a better understanding of their actions and agree to abide by the safety rules and procedures. Unsafe behavior is not acceptable in a science classroom.

Safety in the Elementary Classroom

High-quality science education demands that students participate in a wide variety of science investigations, including demonstrations, experiments, engineering tasks, and other activities. Kindergarten through Grade 5 students can perform these activities in the classroom or on a playground, when appropriate. Safety reminders are provided for teachers within lessons. These should be regarded as the minimum safety precautions, and teachers may elect to implement additional safety precautions. Great Minds insists that teachers and students always follow the safety guidelines listed in this document.

Instructions

Students must follow printed safety instructions and verbal safety instructions given by adults in the classroom.

Behavior

Students must always practice safe classroom behavior. Running, pushing, yelling, or other inappropriate behavior is not acceptable during a science investigation unless running or yelling is an integral part of the investigation. Inappropriate behavior can cause accidents. All supplies, equipment, and living organisms (such as plants and animals) must be handled carefully and respectfully.

Appropriate Dress

When conducting science investigations, students should tie back long hair, secure loose clothing, and wear closed-toe shoes.

Personal Protective Equipment (PPE)

- Goggles—Protective eyewear must be worn by everyone in the classroom (including those who wear eye glasses) whenever science investigations involve
  - projectiles (anything flying through the air, either intentionally or unintentionally),
  - glass (small shards of glass can become projectiles when glass breaks),
  - liquids (splashes of liquids, including water, that can enter the eyes),
  - sharp or pointed objects (for example, bare wires or the ends of meter sticks), and
  - sand or powders (when disturbed, small particles, such as flour or fine sand, can be launched into the air and enter the eyes).
- Gloves—Non-allergenic gloves should be worn by students with open wounds on their hands or when working with plants or animals.
- Aprons—Protective aprons should be worn when there is a danger of splatter or contamination of clothing.

Materials

- Glass—Objects used by students should be made of plastic, wood, or metal whenever possible. Glass breakage can produce extremely sharp surfaces, and glass shards may fly through the air. If glass breakage occurs, students must report the breakage to an adult; students must NOT attempt to clean it up.
- Thermometers—A variety of thermometers are available for use in the classroom. Avoid using thermometers made of glass whenever possible. Thermometers containing mercury (silvery in appearance) should never be used in the classroom. Alcohol thermometers (containing red or blue liquid) are acceptable for classroom use.
- Hot Objects—Students must not touch hot objects, such as incandescent light bulbs or hot plates. Water heated to greater than 140°F should not be used by or near students in a classroom.

- Sharp Objects—Students must wear safety goggles and exercise great care when given permission to use sharp objects, such as scissors, other cutting tools, or wires.
- Bright Lights—If an investigation involves light bulbs, students should be instructed not to stare at lit bulbs. Students should not handle lasers. If the teacher uses a laser for demonstration purposes, the teacher must never point it (or its reflection) toward students.

Food and Drink

- Food—Food should never be brought into the classroom during a science investigation. Outside food can contaminate or become contaminated by classroom materials.
- Drink—Beverages (including water bottles) should never be brought into the classroom during a science investigation. Outside beverages can contaminate or become contaminated by classroom materials. Additionally, spills on the floor can cause slips or falls, disrupt the investigation, or damage classroom materials.
- Taste—Students should never taste or place anything in their mouths during a science investigation.
- Smell—Students should never smell or inhale any substance unless specifically instructed to do so by the teacher.

Workspace

- Cleanliness—The classroom should be kept clean at all times, and students should clean up any messes made during experiments. However, if glass breakage occurs, students must report the breakage to an adult, and students must NOT attempt to clean it up. After each hands-on science investigation, students must wash their hands with soap and water. Science materials and equipment, as well as desks and chairs, should be cleaned daily with disinfectants by school personnel.
- Clutter—The classroom should be kept as clear of clutter as possible. Objects on the floor (such as book bags) are a tripping hazard.
- Electrical Cords—Extension cords should never be used in a classroom. Cords for electric devices should be plugged and unplugged by an adult, and the device should be securely placed so that the cord does not create a tripping hazard. Cords should never be on the floor, even if they are covered with tape or a rubber strip.

Internet Use

If students are allowed to conduct scientific research on the Internet, their activity should be supervised to ensure it conforms to school and district policies.

In addition to these guidelines, teachers should closely follow their school's or district's health and safety guidelines. For additional information on safety, there are many resources that can be found online and in print. Two such resources are the National Science Teachers Association (www.nsta.org) and the Science Safety Handbook for California Public Schools (http://gmscience.link/1118).

Materials

Great Mind Science provides hands-on experiences that allow students to engage in science activities using the Science and Engineering Practices. Materials kits have been developed to support these experiences and will be available through a supplier. These kits suit a variety of budgets, from full kits that provide all required materials to “science on a dime” kits that supply only essential materials that are not readily available in stores. A list of inexpensive materials that teachers can purchase is provided. All kits will provide access to a rich science experience for all students regardless of a school’s budget.

Materials kits will be organized by module and delivered in bins. Reusable materials can be stored from year to year in bins for easy access. Refill kits will be available to replace consumable supplies. A materials list containing any necessary materials and a summary of the preparation required is provided in each lesson set.

Great Minds supports smart environmental practices. Schools are encouraged to reuse, recycle, or compost materials when they can. Visit California’s Department of Resources Recycling and Recovery (CalRecycle) website for information about recycling and reducing school waste: http://gmscience.link/1119.

Materials listed for Grade 4 modules have no special disposal requirements. When materials have such requirements, disposal protocols will be provided. For guidance on disposal of chemicals and other material wastes, consult the Science Safety Handbook for California Public Schools: http://gmscience/1118.

Assessments

Assessing student progress toward mastery is key for student development and teacher planning. Formal and informal assessment opportunities are identified throughout the Great Minds Science curriculum. The goal of each assessment is to identify what scientific knowledge and skills students have gained. For formative assessment opportunities, that may mean that some students need time to gather their thoughts before sharing. In formal or summative evaluations, it may be necessary to read items to some students, modify assessment items while preserving scientific rigor, or allow students to answer verbally with a scribe to evaluate scientific understanding.

Discussions

Class discussions are an important component of the Great Minds Science curriculum. Whenever possible, discussions should be student driven and teacher facilitated. Lessons include sample teacher questions as well as sample student responses. This format is not intended as a script; rather, they should be considered a tool to support questioning strategies that assess students’ knowledge and skills, promote student-to-student discourse, and guide progress through a module. Because Great Minds believes that student discussions are a crucial component of active learning, teachers should consider giving students ample time to think and formulate answers or organize their thoughts by jotting them down before answering. Students can also share and discuss initial responses with a partner before sharing with the class.

English Language Development

The Great Minds Science Approach to English Language Development

While supporting language development is important for all students, it is especially important for English learners and nonstandard English speakers studying science. Students make meaning of language when they interact with new terms in the context of coherent, hands-on experiences in the science classroom. Great Minds Science lessons include suggestions for supporting English language development through best practices aligned with California English Language Development (ELD) Standards. These supports are designed to do the following:

- Explicitly introduce important academic and domain-specific language, providing students with opportunities to understand new terms by hearing the correct pronunciations, applying morphology, relating them to synonyms and cognates, and discussing multiple meanings
- Enable students to relate new terms to prior knowledge using models, pictures, and graphic organizers
- Scaffold students' increasing independence with terms through supports such as word banks and sentence frames for speaking and writing
- Provide opportunities for oral language development through collaborative conversations

English Language Development Standards

The California ELD Standards provide guidelines to foster English proficiency. The standards outline three levels of English proficiency: emerging, expanding, and bridging. Teachers can adapt the supports provided in Great Minds Science lessons based on individual students' proficiency levels. Relevant California ELD Standards are cited in the English language development supports within each lesson.

Transferable Supports for English Language Development

Great Minds Science builds teachers' capacity to support students with a combination of generalizable best practices and lesson-specific examples of those practices in context.

Lesson-specific supports are located in the Teacher Edition of lessons as text boxes titled Support for English Language Development. Some appear in the body of the lesson, while others appear in the margin. Inline supports provide strategies beneficial to most students, such as explicit introduction to new terms and collaborative conversation. Margin supports provide targeted scaffolds for students who need more support. Additionally, each module includes an appendix titled Domain-Specific Words, General Academic Words, and Spanish Cognates. Though these appendices are not comprehensive, they list many important words and Spanish cognates, when available.

Teachers should use their expertise to apply best practices for English language development. The following list describes research-based practices that teachers can customize to meet students' needs.

Collaborative conversations

Class discussions help students make meaning of science, but English learners may be hesitant to participate in whole-class conversations. Creating opportunities for all students to speak and listen to their peers in varied contexts (pairs, small groups, and whole class) helps English learners build their conversational and academic language skills. For more details on routines for collaborative conversations, see the Resources: Instructional Routines section of this Implementation Guide.

Grouping

Grouping students who speak the same native language at complementary proficiency levels can provide additional scaffolding by allowing English learners to converse in their native language, supporting English comprehension and understanding.

Explicit Introduction of Terminology

Explicitly introducing important terms creates a rich base for understanding these terms. The process of explicitly introducing terms may include the strategies below, which teachers can customize based on the word and students' needs.

- **Oral introduction:** The teacher pronounces the word aloud and students repeat it. This provides direct practice in correct pronunciation and allows students to hear the word several times. Additionally, the teacher can break the word into syllables and students can repeat the word in syllables before pronouncing the full word.
- **Morphology:** The teacher or students identify Greek or Latin roots, prefixes, and/or suffixes in the term and discuss the meaning of each of these parts. For example, for the term *interact*, the teacher may say, "The word *interact* has two parts. The prefix *inter-* means together or among, and *act* means to do something." This helps students understand new terms while building skills for breaking down words into morphemes (the smallest part of a word that holds meaning). It may be helpful to keep a running list of roots, prefixes, and suffixes in the classroom so students can refer to them and use them in future word analysis.
- **Cognates:** If possible, the teacher provide a cognate for the term in students' native language.
- **Alternate definitions:** The teacher provides a student-friendly definition or explanation of the term. For example, for the word *dam* the teacher may say, "A dam is a wall that blocks water from flowing." Associating *dam* with the familiar concept of a wall will develop students' understanding by connecting it to something they already know.
- **Varying contexts:** The teacher uses the word in more than one context. For example, a teacher introducing the word *layer* may say, "The word *layer* can be used in different ways. For instance, there can be layers in a cake. Each level of the cake is a layer. Or, if you are cold, you may put on another layer of clothing, such as a coat or sweater."
- **Images or acting out:** While referencing words, it is often helpful to provide a relevant image or act out the word. For example, when teaching the word *canyon*, providing several pictures of canyons will help students associate the images with the word.

Sentence Frames and Word Banks

When English learners are asked to use a new word in oral discourse or in writing, scaffolding beyond explicit introduction may be necessary. Sentence frames and word banks can support students as they use terms in context and develop proficiency with the structure and syntax of English. The process of introducing new sentence frames and word banks may include the strategies below, which teachers can customize based on the task, terminology, and students' needs.

- **Frame:** The teacher reads the sentence frame aloud and students repeat through echo or choral reading. The frame should include the new target word, so students fill in surrounding content and not the target word itself. This scaffolds students' use of new terms and allows for varied responses.
- **Sample sentence:** The teacher reads a sample sentence utilizing the frame and students repeat it.
- **Frame with word bank:** The teacher provides the sentence frame with one or more words missing and asks students to complete the frame. This strategy can be customized to provide more support or a greater challenge by providing a bank of words that includes basic terms for English learners or challenging terms for advanced students. For example, for a sentence including the target term *observed*, the frame might be "We took our pet to the veterinarian after we observed that he was _________." The word bank might include varied words and phrases such as *acting strangely* or *sleeping more than usual* for English learners and *feverish* or *lethargic* for advanced students.
- **Independent application:** Students write their own sentences using the frame, or they confer with a partner before writing it.
- **Partner sharing:** Students share their sentences aloud with a partner. This allows all students to practice using the term verbally. Creating opportunities for all students to orally share their ideas enables practice and reinforcement of academic vocabulary and syntax.
- **Class sharing:** The teacher pre-selects several students to share sentences with the class. Instead of relying on volunteers, the teacher endeavors to hear from all students over the course of several days or a week. It may be helpful to prepare students to be called upon to answer a certain question. This will allow them to prepare an answer more confidently and avoid feelings of being taken by surprise.

Teachers may create reusable sentence frames for tasks and concepts that are encountered frequently in the classroom. For example, students are asked what they notice and wonder about an image or text in multiple Great Minds Science lessons. Students may use sentence frames like "I notice _________" and "I (think/wonder) _________ because I see _________." Students can use these sentence frames every time they complete a notice and wonder task, gradually increasing their independence as they become more proficient with the language.

Supporting Diverse Learners

Great Minds Science believes that student engagement enables students to wonder about the world and empowers them to make sense of it. To ensure a rich experience for all students, specific differentiation strategies are provided throughout each module. Detailed below are general strategies and best practices that will help all students access the curriculum and uncover deep scientific content.

Student Grouping

There are many ways to group students, and every teacher knows what works best for their class and students. When grouping diverse learners, it is important to consider the task. Grouping students of different ability levels works well when performing a leveled task or a task in which students can be assigned a specific role. When grouping students this way, the teacher should maintain control over the dispersal of materials to ensure each student receives an appropriate assignment (reading, data set, role). This allows all students to participate and share in a part of the whole, reinforces the idea that each individual has something to contribute, and encourages a positive classroom culture.

Teachers should consider grouping students of the same ability level when students need to work together to complete a task or solve a problem. For example, this strategy works well when different students should read portions of the same text or when students must work together during an engineering task. Grouping students this way provides an opportunity for the teacher to observe cooperation skills and student flexibility.

Grouping students of the same ability levels also allows students who may need accommodations or modifications to work together as an independent group to complete a task. Creating opportunities for students who have difficulty working autonomously encourages participation, builds confidence, and leads to a sense of accomplishment when a task is completed. If these students struggle with group dynamics, teachers should allow time for them to organize, plan, and start on their own before stepping in to provide guidance.

Reading Complex Text

Many science texts are both qualitatively and quantitatively complex. Digital tools may be helpful for teachers who want to increase student participation in reading activities and class discussions. Several text-to-speech reading applications, such as Read&Write for Google Chrome™, are available to install on computers, tablets, and phones. These reading supports provide opportunities for English learners and striving readers to fully participate in class activities. Another option is a teacher-facilitated reading group in which an adult reads to students. This option enables the teacher to check for comprehension throughout the reading. Additionally, students can read a text multiple times, focusing on a distinct purpose for each read. Multiple reads also allow students to become more comfortable with complex text.

Video

Videos are useful tools to increase comprehension of concepts that can be difficult to grasp through text alone. Providing transcripts of videos may be helpful to some students. Transcripts can also be highlighted to identify key concepts or text or allow students to easily access important information. Transcripts should be offered after the initial viewing so that students can focus on the video without becoming distracted or trying to read along.

Models and Investigations

Developing and using models and carrying out investigations are practices that are used throughout each module of the Great Minds Science curriculum. Students may benefit from pre-cut, pre-drawn, or partly assembled components when drawing models or using patterns. Provide only what is needed, as students learn best when completing the majority of the model or investigation themselves.

Some materials used while making models and carrying out investigations may need to be modified for students with tactile sensitivities. Items such as sand, gravel, soil, construction paper, and others may limit participation for some students. Providing rubber gloves may help some students, while others may need to be assigned a group role that does not involve handling the materials. Examples of such roles include taking pictures, videoing the group's discussions and work, or being the group reporter by documenting the steps of building a model or performing an investigation. The goal is to ensure all students have an active role during the modeling process or investigation.

Resources

Instructional Routines

An instructional routine is a classroom procedure that supports the development of content knowledge and academic skills. An instructional routine provides students with a structured approach to thinking about a topic, question, or idea. The routines suggested in Great Minds Science lessons help students think about science in different ways to build content knowledge, deepen understanding, and develop critical thinking skills. Instructional routines increase student engagement and provide practices to make students' thinking and learning visible.

The following tables describes routines that appear frequently in Great Minds Science lessons. Although lessons provide examples of how to use routines, teachers should use their expertise to select routines that will meet students' needs for each lesson's tasks.

Collaborative Conversation Routines

Routine	Purpose	Grouping	How it Works
Inside–Outside Circles	**Inside–Outside Circles** allows students to respond to questions or talk about information with a variety of students in a structured manner.	Whole group, then pairs	1. For Inside–Outside Circles, the class is divided in half. Half the class becomes the inside circle, and the other half the outside circle to form two large, concentric circles. 2. Students in the inside circle face students in the outside circle. 3. Announce a topic, pose a question, or have students prepare a question related to a concept. 4. Students in each pair (one student in the inside circle and one student in the outside circle) take turns answering the question or discussing the topic. 5. Once sharing has finished, one circle is rotated so students face new partners for a new question or topic.
Mix and Mingle	**Mix and Mingle** offers an active way for students to orally share ideas about a text or concept.	Whole group, then pairs	1. Announce a topic, pose a question, or have students prepare a question related to a concept. 2. Students circulate, then pair up with a peer and share their responses. 3. Students circulate to stand with a different peer, and then discuss responses to the same question or a new question. Optional: Use a cue such as music or chanting to indicate when to stop circulating and pair up. To provide additional think time, have students stand back to back with a partner, think about the question, and then turn to face their partner and discuss.

Routine	Purpose	Grouping	How it Works
Question Corners	**Question Corners** provides a way for students to express and support their claims.	Small groups, then whole group	1. Present a debatable statement or question. 2. In each corner of the classroom, post a response or opinion. Students move to the corner that best represents their opinion. 3. Students discuss the reasons why they chose their corner. 4. After listening to one another's reasoning, students have the option of moving to another corner, but they must explain their rationale for moving.
Response Techniques	**Response techniques** encourages whole-class engagement while enabling teachers to conduct quick, formative assessments of student understanding.	Whole group	Pose a question and then use a technique to elicit quick responses from a variety of students such as one of the following: • Equity sticks (recommended for open-ended questions): Call on students by randomly selecting names from a container that holds all students' names on slips of paper or craft sticks. • Response cards (recommended for questions with a closed set of possible responses): Students select a response from a set of pre-printed response cards, then hold up their cards for the class to see. • Nonverbal signal (recommended for questions with a closed set of possible responses): Students respond with a general signal (e.g., the American Sign Language [ASL] sign for yes or no) or a situation-specific signal (e.g., the ASL letter *P* when they hear details about a story's problem). To encourage independent thinking, suggest that students make the signals close to their chests. • Whiteboards (recommended for open-ended or closed questions with short written responses): Students write responses on individual whiteboards or other erasable boards, then hold up their responses for the class to see.
Socratic Seminar	A **Socratic Seminar** is a student-led, academic conversation. This routine allows students to use their speaking and listening skills to express and deepen their science content knowledge.	Whole group	1. Students prepare for dialogue by reviewing and reflecting upon relevant materials or texts. 2. Students engage in pre-writing to stimulate and organize thinking about the topic. 3. Ask an opening question. 4. Students form a dialogue circle and engage in collaborative speaking and listening using evidence from their resources. 5. Provide prompts as needed to stimulate the dialogue. 6. Students complete a post-writing activity to answer questions such as What new knowledge did you gain? and How did your thinking change?

Routine	Purpose	Grouping	How it Works
			7. Students debrief the activity, reflecting upon what went well and what needs improvement.
Think–Pair–Share	**Think–Pair–Share** allows individual students to consider their thoughts about a question and then collaboratively discuss the question with peers.	Individuals, then pairs, then small groups or whole group	1. Pose a thought-provoking question. 2. Give students time to think. 3. Students share their responses with a partner. 4. Then, pairs share their responses with small groups or the whole group. Not all students need to share their responses in the larger group. Variations: • Think–Pair: Complete the same procedure without the small or whole-group sharing. • Think–Pair–Square: Students conduct a Think–Pair and then join a second pair, sharing in groups of four. • Jot–Pair–Share: Students quickly jot their thinking prior to sharing with a partner.
Whip Around	**Whip Around** serves as a quick check for understanding of each student's thinking or a culminating reflection on learning.	Whole group	1. Pose an open-ended question. 2. Individual students jot down or think about their answers. 3. Students share their responses one after another until all students have shared their answers. 4. If students wrote their answers, each student can strike out her or his answer if someone else says it first.

Written Response Routines

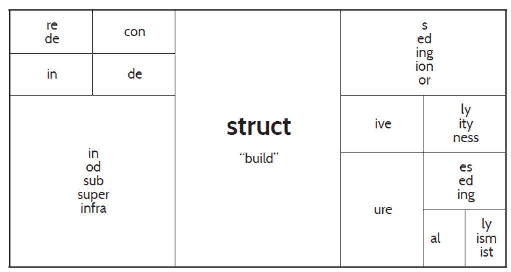
Routine	Purpose	Grouping	How it Works
Chalk Talk	**Chalk Talk** is a silent conversation that helps students organize their thinking and fosters universal participation.	Small groups or whole group	1. Write questions on the board or pieces of chart paper. 2. Students respond to the questions, as well as to others' follow-up questions and responses, by writing directly under each question on the board or paper.
Gallery Walk	**Gallery Walk** deepens engagement and understanding by allowing students to share their work with peers in a gallery setting.	Individuals, pairs, or small groups	1. Post work around the room. The work can include group investigation plans, small group Graffiti Walls, group models, etc. 2. Students circulate, closely viewing the work. They can discuss with peers or record written observations. (Optional: Some students stand by their work to present it to viewers.) 3. Students debrief through discussion and/or writing.

Routine	Purpose	Grouping	How it Works
Give One–Get One–Move On	**Give One–Get One–Move On** engages all students in identifying and sharing key learning.	Pairs	1. Students record key ideas on index cards or sticky notes. 2. Students circulate and locate a partner with whom to share their key ideas. 3. Announce "Give One" to indicate that students should swap ideas and "Get One" from another student. 4. Announce "Move On" to indicate that students should circulate again to find a new partner and repeat the process, explaining the new idea to the new partner.
Graffiti Wall	**Graffiti Wall** helps students organize and deepen their thinking as they collaboratively explore key concepts. This routine supports visual learners and promotes collective learning.	Small groups	1. Give small groups a large piece of chart paper. 2. After investigating, reading, or discussing a task, students record their ideas and learning on the paper through symbols, illustrations, words or phrases, and quotations. The routine can be scaffolded by specifying a minimum or maximum number of symbols or phrases to be included on the wall.
Praise, Question, Suggestion	**Praise, Question, Suggestion** is a routine that elicits authentic peer-to-peer feedback.	Pairs or small groups	1. Each student shares work with a partner or the small group. 2. The partner or group members give(s) specific positive feedback, ask(s) a question, and offer(s) a suggestion. Optional: Establish a focus for peer feedback (e.g., one or more criterion from the rubric). 3. Each student summarizes her or his plan for revision based on the feedback.
Quick Write	**Quick Write** is a brief written response that helps students reflect on a topic and teachers assess comprehension. It can be used at the beginning of a lesson as a warm-up, during the middle of a lesson in response to an idea or experience, or at the end of a lesson to summarize key ideas.	Individuals	1. Select a purpose for the writing that is tied to the content area. 2. Students listen to the prompt and are instructed to write a response by jotting down whatever comes to mind. 3. Students are given a short amount of time to write. 4. Students can share with others, or their ideas can be collected to inform teaching.

Routine	Purpose	Grouping	How it Works
3–2–1 Response	**3–2–1 Response** encourages students to reflect on a text or new learning and provides formative assessment data for teachers.	Individuals	1. Display a 3–2–1 prompt. 2. Students write responses to the prompt and then discuss. Below are examples of 3–2–1 Response prompts. Example A • 3 most important ideas • 2 supporting details • 1 question Example B • 3 things you learned • 2 questions you still have • 1 connection to previous knowledge
Snowball	**Snowball** can be used to predict, summarize, justify, explain, or think critically in response to a content-related question or prompt. This routine provides a low-risk engagement opportunity for students because responses are kept anonymous.	Whole group	1. Students anonymously write a response or answer to a prompt or question on a piece of paper. 2. Students crumple the paper into a "snowball." 3. Students throw their snowballs across the room for a short time period. 4. After students have thrown several snowballs, they select the one closest to them and prepare to share the response written on the paper with the class.

Vocabulary Learning Routines

Routine	Purpose	Grouping	How it Works
Frayer Model	A **Frayer model** helps students identify and define unfamiliar concepts and vocabulary by looking at essential characteristics, examples, and nonexamples.	Individuals, pairs, or small groups	1. Select a concept or vocabulary term for further study. 2. Students record characteristics, examples, and nonexamples of the concept or term to create a working description or definition. As an extension activity, students sketch their examples and nonexamples.
Link Up	**Link Up** helps students understand the connection between two identified vocabulary terms.	Pairs, then whole group	1. Give each student an index card with a vocabulary term written on it. 2. Specify relationships that different terms might have to each other. 3. Students circulate and discuss with each person they meet whether their terms are related.

Routine	Purpose	Grouping	How it Works
			4. Once students identify someone with a related term, they pair with that person. 5. As a whole group, students debrief. For example, pairs share the relationship between their terms.
Morpheme Matrix	A **Morpheme Matrix** deepens students' knowledge of roots and affixes. It can be used to introduce a new term or to build upon a known root.	Individuals, pairs, or small groups	1. Introduce a term and encourage students to break the term down into its root(s) and affix(es). 2. Explicitly teach the meaning of the root and/or affixes. 3. Encourage students to brainstorm additional words that have the same root. Students create a Morpheme Matrix showing related words. 4. Discuss the meaning of new terms and use them in different contexts. Example: *reconstruct* 
Outside–In	**Outside–In** can be used to determine word meaning from context and morphology such as roots and prefixes.	Individuals, pairs, small groups, or whole group	1. Select an unfamiliar word from a text. 2. Ask students to discuss what clues outside the word (context) reveal about the word's possible meaning. 3. Ask students to discuss what clues inside the word (e.g., roots, affixes) reveal about the word's possible meaning. 4. Students draft possible definitions and then verify them using reference materials.
Images	**Images** support the acquisition and understanding of vocabulary terms.	Whole group	1. Select an image for students to view that represents the desired vocabulary term of study. Images can include photographs, diagrams, and illustrations. 2. Students label parts within the image and/or add annotations showing additional information or connections. 3. Students discuss what the image represents.

Routine	Purpose	Grouping	How it Works
Relationship Maps	**Relationship mapping** allows students to determine connections between multiple terms that have a significant relationship to each other.	Individuals, pairs, or small groups	1. Provide students with a set of related terms. 2. Students determine connections between the terms. 3. Students create a graphic organizer to represent how the terms relate. The shape will vary depending on the word relationships (e.g., Venn diagram, spoke wheel) This routine is often referred to as **concept mapping**.
Word Wall	A **Word Wall** supports students in tracking, using, and deepening understanding of vocabulary.	Whole group	1. Designate a space on the classroom wall. 2. When students encounter key vocabulary, have them use sticky notes to add words, definitions, illustrations, and examples to the space. 3. Have students refer to the Word Wall to incorporate vocabulary into discussion and writing.

Text-Based Routines

Routine	Purpose	Grouping	How it Works
Choral Reading	**Choral Reading** supports fluency and comprehension of a challenging text.	Whole group	1. Provide copies of a text or project a large version at the front of the classroom. 2. Read a passage aloud to model fluent reading. Ask students to use their eyes or an index card to follow along with the text. 3. Reread the passage as all students read the text aloud in unison.
Jigsaw	**Jigsaw** allows students to study one section of a text (or task) and then share with students who studied other sections. This gives all students access to the ideas from the full text without requiring them to read the entire text. It also encourages collaborative learning.	Small groups	1. Divide a text (or task) into multiple pieces. 2. Divide students into "home" groups. Assign each student in a home group a specific piece of the text (or task). 3. Students regroup according to their assignment from Step 2, meeting in "expert" groups with others who share the same assignment. 4. Students work collaboratively in their assignment-based groups to become experts on their assigned text (or task). 5. Students then return to their home groups. Each group member shares her or his expertise. Variation: One Stay, Three Stray Students from one Jigsaw group visit other groups and then report back to the Jigsaw group.

Routine	Purpose	Grouping	How it Works
Partner Reading	**Partner Reading** is a cooperative activity that encourages peer-to-peer learning. It is a routine for fluency practice only when students have previously read the text.	Pairs	Option 1: 1. Partner A reads the assigned passage while Partner B listens and comments on a specified aspect of the reading (e.g., accuracy or fluency). 2. Partner B reads the same passage while Partner A listens and comments. Option 2: 1. Partner A reads a page, paragraph, or section. 2. Partner B reads a different page, paragraph, or section. 3. Each partner shares feedback after hearing the other read.

Speaking and Listening Supports

Classroom Expectations

Scientific discourse is integral to the California Next Generation Science Standards and requires a classroom environment where all students productively share their ideas and questions. During science discussions, remind students of classroom expectations for speaking and listening, including the Speaking and Listening Anchor Standards and their grade-level counterparts (CDE [2010] 2013, 26)* as listed below.

Comprehension and Collaboration

- CA CCSS.ELA-Literacy.CCRA.SL.1: Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.
- CA CCSS.ELA-Literacy.CCRA.SL.2: Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.
- CA CCSS.ELA-Literacy.CCRA.SL.3: Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric.

Presentation of Knowledge and Ideas

- CA CCSS.ELA-Literacy.CCRA.SL.4: Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.
- CA CCSS.ELA-Literacy.CCRA.SL.5: Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations.
- CA CCSS.ELA-Literacy.CCRA.SL.6: Adapt speech to a variety of contexts and communicative tasks, demonstrating command of formal English when indicated or appropriate.

Collaborative Conversation Prompts

During classroom conversations, use prompts such as the following to support students' communication. Encourage students to ask similar questions of their peers.

Clarification

- What do you mean by ______?
- Can you say more about that?
- Could you summarize that in your own words?
- What is your main point?
- What difference does that make?

Reasoning

- Why do you think that?
- How did you come to that conclusion?
- What do you think caused that?
- If what you said is true, then how do you explain ______?
- What would be an alternative to ______?

Evidence

- What is your evidence?
- Could you give us an example?
- What observations or data support your thinking?
- How do you know?

Collaboration

- Who can summarize what ______ just said?
- Who can build on that idea?
- Do you agree with ______? Disagree with ______?
- Did ______ change your mind, or are you sticking with your original answer?
- Does anyone see this another way?
- How are these two ideas alike? How are they different?

For additional reading on science discussions in the classroom, see the NSTA article "Making Time for Science Talk" by Mark J. Gagnon and Sandra K. Abell (2007) (http://gmscience.link/1148) or *Talk Science Primer* by Sarah Michaels and Cathy O'Connor (2012) (http://gmscience.link/1149).

Socratic Seminar Resource

Overview

Socratic Seminars focus on the importance of questioning. Each seminar is based on a rigorous question that pushes students' thinking, allowing students to synthesize and extend their learning through exploration and debate. Students' conversations should go beyond summarizing learning they have done in previous lessons.

Student and Teacher Actions

Student Actions

- Respond to peers, pose new questions, and offer new lines of inquiry.
- Practice and develop skills such as listening, responding, asking questions, paraphrasing, summarizing, citing evidence, making connections, and building ideas based on the opening question.

Teacher Actions

- Ask follow-up questions to elicit greater understanding of the topic, bring out viewpoints, etc. (see sample questions below).
- Remain neutral by not affirming or challenging ideas, verbally or nonverbally. The goal is for students to think for themselves, not just agree because the teacher affirms something.
- Take notes for reflective practice and improvement.
- Debrief with the class after the seminar through questions such as the following:
    - How well did we meet our goals?
    - What worked?
    - What didn't work?

Facilitating an Effective Socratic Seminar

Facilitators listen attentively, sharing questions and observations only as needed. The facilitator (the teacher) asks the opening question and then observes as students initiate a discussion. If the initial question does not spark discussion, the teacher should encourage students to draw from their notes and pre-writing. If significant wait time has passed, the teacher may consider asking a new question.

The facilitator's three early roles include the following:

- Questioner: Ask an open-ended, thought-provoking question.
- Clarifier: Ask follow-up questions designed to increase clarity and specificity of responses.
- Process Coach: Coach students to go deeper, work together, build cohesion and rapport, etc.

General facilitator actions include the following:

- Insist that answers are clear by directing students to rephrase as necessary.
- Insist on citations, text evidence, and strong reasoning.
- Put a student "on hold" (i.e., pause him or her from speaking) to balance contributions.

- Invite additional viewpoints or opinions.
- Suggest a Think–Pair–Share.
- Track, tally, or map participation.

The facilitator may consider posing questions at opportune times to enhance collaboration such as these:

- Do you agree with ______? Disagree with ______?
- Did ______ change your mind, or are you sticking with your original answer?
- Have you heard an answer that is different from yours?
- Does anyone see this another way?
- How are these two ideas alike? Different?
- Can you summarize what ______ just said?
- Does anyone have a different understanding of the problem?

Energy Overview

Energy is a thread that binds the Grade 4 modules together. Energy is one of the most useful, interesting, and powerful concepts that people have uncovered. Energy is required to make everything happen, and all living things require energy to stay alive. Although the word and concept of energy first appeared just over 200 years ago, it has become commonplace in everyday language throughout the world. The concept of energy spawned a series of advancements that ignited the Industrial Revolution. Modern understanding of energy continues to propel the world forward in such fields as thermodynamics, acoustics, and solar technology.

Defining Energy

Energy is intangible—it cannot be touched, seen, heard, smelled, or tasted. However, sensory receptors can detect various phenomena that indicate the presence of energy.

A formal definition of energy is the ability to do work, where work is equal to the force applied an object multiplied by the distance the object moves. Instead of searching for a clear definition, it is useful to consider what we know about energy. The following list summarizes important statements about energy.

1. Energy is needed to make things happen. Everything that happens everywhere involves an exchange of energy.
2. All energy is fundamentally the same. Energy can be manifested as different phenomena, and people may refer to these as different forms, types, or indicators of energy. Classifying energy phenomena helps people improve their understanding of energy, make predictions about events, and develop technologies.
3. Energy can be transferred from object to object and from place to place.
4. Energy can be transformed from one “form” to any other.
5. Energy can be quantified. People can measure physical aspects (e.g., mass, speed, temperature) and then calculate the associated energy.
6. Energy is conserved. It cannot be created or destroyed. The total amount of energy in a closed system remains the same.

Conservation of Energy

The real reason that energy is such an important concept is based in the idea that energy is a conserved quantity. That is, energy cannot be created or destroyed, but can move around and change forms.

A challenge when trying to analyze the energies involved in a system is keeping track of all the different forms of energy. Some forms are relatively obvious and easy to quantify, but others can be subtle and difficult to quantify. To account for all the energies in a situation, extraordinary "bookkeeping" is often required.

Perhaps Richard Feynman summarized conservation of energy best during the famous lecture he delivered in 1961. These were some of his major points about the Law of Conservation of Energy:

- "[It] is a most abstract idea because it is a mathematical principle"
- "[I]t says that there is a numerical quantity which does not change when something happens."
- "[I]t is exact so far as we know."
- "It is not a description of a mechanism, or anything concrete."
- "[I]t is just a strange fact that we can calculate some number, and when we finish watching nature go through her tricks and calculate the number again, it is the same."

Classifying Energy

Classifying forms of energy helps develop deeper understandings of energy. The three basic classifications of energy are kinetic energy, potential energy, and light. The classifications and some examples are summarized in the figure on the next page.

1. **Kinetic energy** is the energy of motion (i.e., the amount of energy an object possesses because it is moving).
2. **Potential energy** is stored energy (i.e., the amount of energy stored by mass and force that can be released later).
3. Although we have not yet determined the exact nature of **light**, we often consider it to be a pure form of energy.

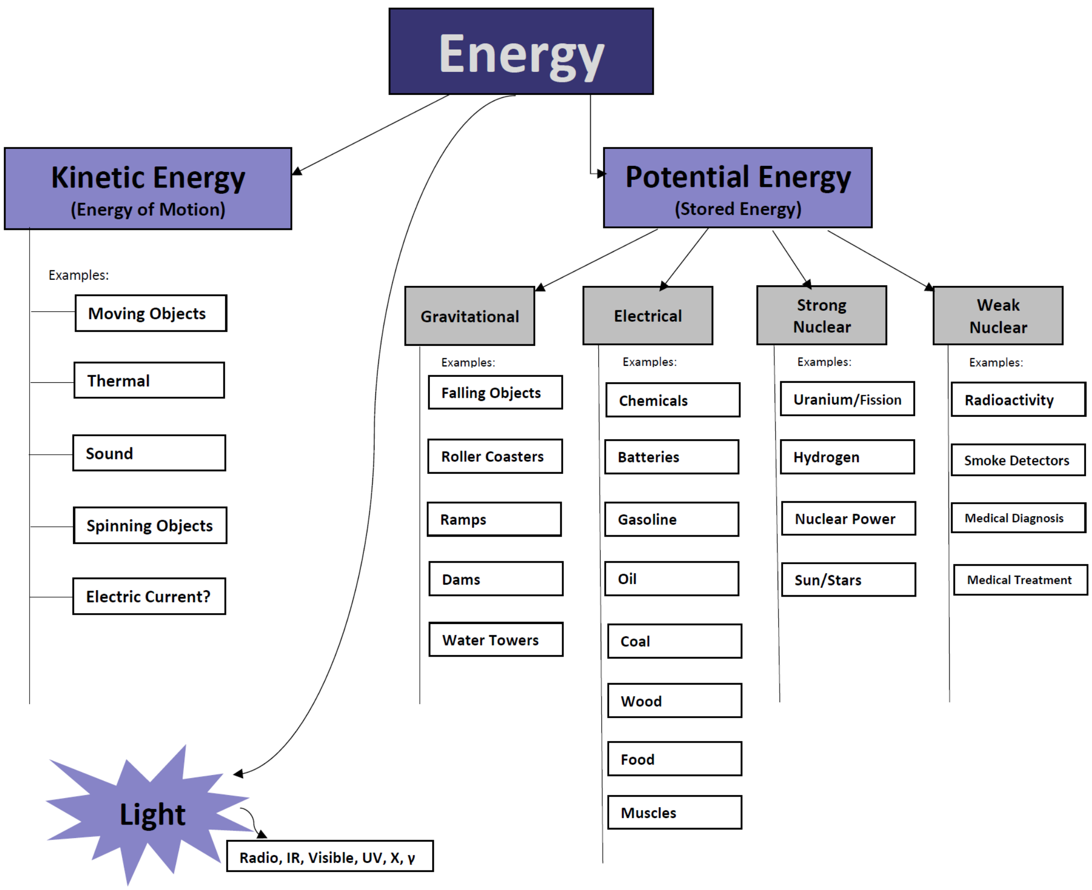
Kinetic energy

There is only one basic type of kinetic energy: that which is caused by motion. Any moving object has kinetic energy, whether the object is moving from place to place, rotating, or vibrating. The amount of kinetic energy an object has is affected by both its speed and its mass. The mathematical formula for kinetic energy is $KE = \frac{1}{2}(\text{mass})(\text{velocity})^2$.

Many observable "forms" of energy are actually subclassifications of kinetic energy. For example, sound is the result of a pattern in the motion of air molecules. Repeated collisions of air molecules cause the kinetic energy to spread away from the source. Thermal energy is the result of vibration in the molecules and atoms of a material. When the thermal energy of an object is increased or decreased, we call that process heat transfer.

Potential energy

Potential energy is stored in many ways. Potential energy is stored by a force that can be later released to act on a mass. Since there are only four forces known to us, potential energies can be classified by the force that causes them. These forces are the gravitational force, the electric force, the weak nuclear force, and the strong nuclear force. The two types of potential energy encountered most often in everyday life are gravitational potential energy and electrical potential energy.



Profiles in Science, Engineering, and Technology

This resource includes profiles to broaden students' knowledge of science and its applications. These profiles highlight the iterative nature of scientific progress and the diversity of people who make significant contributions. They are organized by connection to module topics. Teachers can use this resource in a variety of ways, including sharing relevant information during lessons or allowing students to select individuals for further research.

Module 1

Luis Walter Alvarez, Experimental Physicist (1911–1988)

Why did dinosaurs become extinct? Based on research conducted with his son, Walter, Luis Alvarez postulated that dinosaur extinction was due to a large asteroid impact. An experimental physicist, Luis Alvarez made many contributions to his field. He was awarded the Nobel Prize in Physics in 1968 for his use of a liquid hydrogen bubble chamber to discover new subatomic particles and resonance states—just one of his contributions to science. His son, a geologist, discovered a layer of clay found worldwide that was thought to mark the transition between the Mesozoic and Cenozoic eras. Alvarez compared levels of iridium—which is typically associated with meteorite impacts—in the clay to the levels of iridium in other layers. From this information, the father and son theorized that an asteroid or comet struck the Earth and caused a mass extinction.

To learn more, students can read the chapter "Killer Asteroid" from *Extinction* by Sonya Newland (2013) (http://gmscience.link/1120) and the *Encyclopædia Britannica Online* article "Luis Alvarez" (2017a) (http://gmscience.link/1121).

Benjamin Banneker, Surveyor and Astronomer (1731–1806)

Benjamin Banneker was a self-taught astronomer and mathematician, reading books borrowed from family and neighbors. As a surveyor, Banneker used his mathematics skills to plan roads for Washington, DC. When was 20, he resolved to make his own clock. He took apart a friend's pocket watch and began to carve the necessary components out of wood. Amazingly, his wooden clock kept accurate time for over 50 years. Banneker is well known for using observations of patterns in nature and his understanding of astronomy to write a successful almanac for the mid-Atlantic states, in which he computed eclipses, tides, and daily star and planet positions. Unlike better known astronomers, Banneker successfully predicted a 1789 solar eclipse.

To learn more, students can read *Benjamin Banneker: Pioneering Scientist* by Ginger Wadsworth (2003) (http://gmscience.link/1122) and the Biography.com article "Benjamin Banneker Biography" (2018a) (http://gmscience.link/1123).

William John Macquorn Rankine, Civil Engineer (1820–1872)

Although the first known dam was built in present-day Jordan over 5,000 years ago, significant advancements in the science and engineering of dam building were made in the mid-1800s by Scottish engineer William John Macquorn Rankine. While Rankine is best known for his many contributions to the study of thermodynamics, he was also responsible for the improvement of dam engineering through his study of soils, hydrodynamics, and building materials such as iron. His work laid the foundation for modern civil engineers, bringing recognition to the field of engineering. Engineering and building of dams continues to improve; within the last sixty years, scientists have begun to focus on minimizing the harmful effect of dams on the ecosystems surrounding them.

To learn more, students can read the *Encyclopædia Britannica Online* article "William John Macquorn Rankine" (2017b) (http://gmscience.link/1124).

Diana Trujillo, Aerospace Engineer (1983–)

Learning about the composition of rocks on Mars helps scientists learn more about Earth. When Diana Trujillo moved to the United States from Columbia to follow her dream of working for NASA, she did not know English. Six years later, she had learned the language and earned a degree in aerospace engineering. After graduation, Trujillo began working for NASA on the Mars Curiosity rover project, where she and her colleagues worked to find a way to collect rocks from the surface of Mars. The challenge was for the rover to collect rocks found below a layer of red dust covering the surface of Mars. The team created the Dust Removal Tool to help identify rocks before drilling into them. The rocks on Mars hold information that scientists believe will help understand why life is abundant on Earth but has vanished or never existed on Mars (Cornell 2016a).

To learn more, students can read *Mars Science Lab Engineer Diana Trujillo* by Kari Cornell (2016a) (http://gmscience.link/1125).

Module 2

John Dabiri, Biophysicist and Bioengineer (1980–)

Innovation can come from the most unlikely of places. While observing swimming schools of fish, Nigerian-American biophysicist John Dabiri recognized that fish swim close together in a diamond pattern to maximize their swimming efficiency and minimize the energy they need to expend. Dabiri, a specialist in fluid mechanics, saw that this concept could be applied to vertical wind turbines. Typically, wind turbines are placed at a distance apart to minimize interference, but Dabiri thought that if they were placed in a coordinated pattern similar to the one used by fish, each would benefit from the surrounding turbines. Dabiri's findings could change the way wind farms are designed (Bullis 2013; Burillo-Kirch 2016).

To learn more, students can read the chapter "Bioengineering in Energy" from *Bioengineering: Discover How Nature Inspires Human Designs* by Christine Burillo-Kirch (2016) (http://gmscience.link/1126).

Stephen Hawking, Theoretical Physicist (1942–2018)

Diagnosed with Amyotrophic Lateral Sclerosis (ALS) at the age of 21, Stephen Hawking wasn't expected to live to age thirty. In his 76-year life, Hawking, a brilliant physicist, author, and professor, was known for his discoveries pertaining to science of black holes and relativity. Hawking's radiation theory explains that matter, in the form of radiation, can escape the gravitational pull of a black hole. He theorized that the universe began with energy created by the collision of particles within a black hole at a single point of origin. The particles—and thus the universe—expanded at a rapid rate as energy was released. In an effort to make science accessible to everyone, Hawking wrote many books, including *A Brief History of Time* (1988) and *The Universe in a Nutshell* (2001), and coauthored children's science novels with his daughter Lucy.

To learn more, students can read *Stephen Hawking: Extraordinary Theoretical Physicist* by Karen Latchana Kenney (2015) (http://gmscience.link/1127), *Theoretical Physicist Stephen Hawking* by Kari Cornell (2016b) (http://gmscience.link/1128), and the Biography.com article "Stephen Hawking Biography" (2018e) (http://gmscience.link/1129).

Maria Goeppert-Mayer, Physicist and Mathematician (1906–1972)

Maria Goeppert-Mayer moved to the United States in 1930 after earning a PhD from the University of Göttingen in Germany. She faced discrimination as a female scientist, working in unofficial and unpaid roles for fifteen years before being offered a position as a senior physicist at Argonne National Laboratory. In 1948, Goeppert-Mayer developed a model showing that protons and neutrons were distributed in shells of different energy levels within an atom's nucleus. This discovery helped explain why some elements are more stable than others. In 1963, she became the first woman to win the Nobel Prize for theoretical physics when she shared the award with Hans Jensen, who had made the same discovery concurrently.

To learn more, students can read the Famous Scientist article "Maria Goeppert-Mayer" (2015) (http://gmscience.link/1130).

Chien-Shiung Wu, Nuclear Physicist (1912–1997)

Known as the First Lady of Physics, Chien-Shiung Wu made many significant contributions to the field of nuclear physics. She was born in China to parents who were fierce proponents of education. After Wu moved to the United States in 1936 to further her education, her work on the Manhattan Project led to a discovery essential to the development of the atomic bomb. Among many other accomplishments, Wu disproved a widely accepted law of physics, the law of conservation of parity. Her work earned her colleagues a Nobel Prize in Physics, though she never received the award herself. In 1975, Wu became the first female president of the American Physical Society and remained an advocate for women in science for the rest of her career.

To learn more, students can read the chapter "Chien-Shiung Wu Pioneers Nuclear Research" from *Unsung Heroes of Science* by Todd Kortemeier (2017a) (http://gmscience.link/1131), *Nuclear Physicist Chien-Shiung Wu* by Valerie Bodden (2017a) (http://gmscience.link/1132), and the Biography.com article "Chien-Shiung Wu Biography" (2018b) (http://gmscience.link/1133).

Module 3

Eugenie Clark, Marine Biologist (1922–2015)

Most people would not choose to swim with sharks as an occupation. After studying ichthyology (the study of fish) in the 1940s, Eugenie Clark focused on shark behavior, which eventually earning the nickname Shark Lady. Having learned to swim at age two, Clark credited her Japanese heritage for her love of and curiosity about the sea. Although using scuba diving gear for underwater research was uncommon, Clark used it to observe sharks and refute previous conceptions that sharks had to swim continuously to breathe. She also discovered a natural shark repellent, a chemical released by a species of sole fish to deter sharks. Clark spent much of her career educating people about sharks. Scientists continue to study shark behavior, including its relation to tourism and human interactions.

To learn more, students can read the section titled "Eugenie Clark" in the chapter "Natalie Arnoldi" from *Marine Biology: Cool Women Who Dive* by Karen Bush Gibson (2016) (http://gmscience.link/1134).

Jane Goodall, Animal Scientist and Activist (1934–)

Chimpanzees use tools to get food, just as humans do. This is just one of many extraordinary discoveries made by Jane Goodall. Goodall loved animals as a young girl in England. Before earning a PhD in ethology (the study of animal behavior), she spent several years living in close proximity to wild chimpanzees in Tanzania, Africa. During this time, she learned that chimpanzees use both verbal and nonverbal communication, make tools, work together to get food, and form social groups. She then spent over forty years studying chimpanzees and educating others about the importance of conservation and the ethical treatment of animals.

To learn more, students can read *Animal Scientist and Activist Jane Goodall* by Douglas Hustad (2017) (http://gmscience.link/1135), *Jane Goodall: Revolutionary Primatologist and Anthropologist* by Lois Sepahban (2016) (http://gmscience.link/1136), and the Biography.com article "Jane Goodall Biography" (2018d) (http://gmscience.link/1137).

Roger Payne, Biologist (1935–)

Songs of humpback whales can be heard over twenty miles away and can last for twenty minutes! Roger Payne was the first scientist to study and record the sounds of humpback whales. Along with fellow scientist Scott McVay, Payne used a hydrophone, an underwater microphone, to discover that the sounds made by whales are actually songs used to communicate with other whales. Male humpback whales are particularly vocal. In 1970, Payne released an album of whale songs that became widely popular, sparking public interest in whales and marine biology in general. Scientists continue to research why humpback whales communicate and have recently found a new, low-frequency song possibly related to mating.

To learn more, students can read "Giant of the Seas" from *Whales* by Melissa Gish (2012) (http://gmscience.link/1138).

Charles Henry Turner, Zoologist (1867–1923)

How do insects sense the world around them? Charles Henry Turner, the first African American to earn a PhD in zoology and an authority on animal behavior, developed new observation methods to answer that question. He proved that insects can hear differences in pitch, and honeybees can see color and recognize patterns. He also discovered that some insects can learn new behaviors. Before Turner's work, people knew little about insect senses. Now, scientists are learning more about the unusual capabilities of insects, such as how the ability of bees to see ultraviolet light helps guide them to the center of flowers.

To learn more, students can read the Biography.com article "Charles Henry Turner Biography" (2015) (http://gmscience.link/1139) and the chapter "Charles Henry Turner Discovers Amazing Insect Facts" from *Unsung Heroes of Science* by Todd Kortemeier (2017a) (http://gmscience.link/1140).

Module 4

Ada Lovelace, Mathematician (1815–1852)

The first program for a machine was written in the mid-1800s, long before computers were invented. Ada Lovelace was a talented female mathematician from England and is thought to be the first person to create an algorithm for a calculating machine. The concept of the machine, called the Analytical Engine, was proposed by fellow mathematician Charles Babbage. Though the machine never materialized, Ada's algorithm included what are referred to today as loops and subroutines in computer programming. This type of code helps computers and other high-tech devices process information.

To learn more, students can read *Programming Pioneer Ada Lovelace* by Valeria Bodden (2017b) (http://gmscience.link/1141) and *Ada Byron Lovelace and the Thinking Machine* by Laurie Wallmark (2015) (http://gmscience.link/1142).

Navajo Code Talkers

One of the biggest challenges during World War II was protecting sensitive information. Navajo people communicated in a unique, unwritten language unknown to most people outside of their culture. Over four hundred men were recruited and trained by the U.S. Marines to memorize and communicate via a code based on the Navajo language—a code that proved impossible to decipher by enemy forces and remains the only spoken military code to go unbroken. Amazingly, communication between allies during the Battle of Iwo Jima was conducted entirely through Navajo Code.

To learn more, students can read *Native American Code Talkers* by M. M. Eboch (2016) (http://gmscience.link/1143).

Alan Turing and the Bletchley Park Codebreakers (1912–1954)

During World War II, both sides used codes to communicate, and many resources were dedicated to cracking the codes of the opposing side. Alan Turing, an English scientist and mathematician, worked with a group primarily composed of women at the Allies' codebreaking site, Bletchley Park. Germany was using the complex Enigma machine to encode war communication. Turing created a machine that ran the code through billions of calculations to decipher it. Turing's machine eventually cracked the code, enabling the Allies to read the Germans' secret communications and even spread false information.

To learn more, students can read the chapter "Alan Turing Invents the Modern Computer" from *Unsung Heroes of Technology* by Todd Kortemeier (2017b) (http://gmscience.link/1144) and the chapter "Hands-On Technology" in *Innovators: The Stories Behind the People Who Shaped the World* by Marcia Amidon Lusted (2017) (http://gmscience.link/1145).

Granville Tailer Woods, Inventor (1856–1910)

Granville Tailer Woods obtained nearly sixty patents in his lifetime and became known as "Black Edison" because his achievements rivaled those of Thomas Edison. Among his inventions was the induction telegraph—which he called the Synchronous Multiplex Railway Telegraph—created in 1887. The patent was challenged, and Woods was sued by Thomas Edison, who said the concept was originally his idea. Woods won the lawsuit. The induction telegraph allowed railroad workers to communicate with voice using electrical signals that traveled through a wire. This invention improved the safety of railway systems and was a step toward telephone and wireless communication.

To learn more, students can read the Biography.com article "Granville T. Woods Biography" (2018c) (http://gmscience.link/1146) and the chapter "Problem Solvers Who Set Trains in Motion" in *Trains* by Katie Marsico (2009) (http://gmscience.link/1147).

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