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Chain Reaction: Energy in Motion

NGSS EARLY IMPLEMENTERS

WestEd

A Collaboration of the K–12 Alliance @ WestEd,
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Acknowledgments

Writers

Chelsea Cochran, Science Coordinator, San Diego County Office of Education

Kathy DiRanna, K-12 Alliance Statewide Director, WestEd

Alyssa Nemechek, Core Leadership Team and 4th Grade Teacher, Palm Springs USD

Lana Van, 4th Grade Teacher, San Diego USD

Readers

Ursula Fabiano, 4th grade teacher, Palm Springs USD

Claudia Razo, 4th grade teacher, Palm Springs USD

Field Test Teachers

Alyssa Nemechek, Core Leadership Team and 4th Grade Teacher, Palm Springs USD

Diane Deem, Core Leadership Team and 4th Grade Teacher, Vista USD

Reviewers

Achieve Science Review Panel

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Introduction

The California K–8 NGSS Early Implementation Initiative was developed by the K–12 Alliance at WestEd with close collaborative input on its design and objectives from the California State Board of Education, the California Department of Education, and Achieve. This project was designed to build local education agency (LEA) capacity to fully implement the Next Generation Science Standards (NGSS) as a core subject in the elementary grades (K–5) and as the SBE's preferred integrated model in grades 6–8.

The six-year Initiative provided teachers and administrators with in-depth, content-rich professional development to build leadership capacity and teacher acumen to deliver high-quality 3-dimensional learning for K–8 students. In addition, through collaborations among the K–12 Alliance, Achieve, and others, the LEAs in the Collaborative had opportunities to pilot test new NGSS-aligned tools, processes, assessment item prototypes, and digital and other instructional materials. The LEAs continue to serve as resources for NGSS implementation across California, and in other NGSS-adopting states as well.

This resource presents the conceptual storyline for a unit of instruction at a specific grade level, then focuses on a portion of the storyline called a learning sequence. The learning sequence uses the three dimensions of the NGSS (disciplinary core ideas—DCI; science and engineering practices—SEP; and crosscutting concepts—CCC) to build and deepen student understanding of natural phenomena and design challenges.

Participants in the CA NGSS K–8 Early Implementation Initiative developed and field-tested the lessons in the learning sequence.

Overview

The anchoring phenomenon for this unit is: A Rube Goldberg® machine stalls. In this unit, students recognize that energy transfers and transforms in everyday life as they explore the flow of energy within and between systems. They identify observable changes that occur, where the energy comes from, and where the energy goes. Students investigate energy transfer from place to place and recognize that the faster an object is moving the more energy it possesses. Students investigate energy transformation as the energy source is converted in its actions and apply their understanding by designing a device that transforms energy.

The Performance Expectation(s) addressed in this unit are:

4-PS3-1 Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-3 Ask questions and predict outcomes about the changes in energy that occur when objects collide.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Learning Sequence Narrative

The learning sequence narrative briefly describes what students do in each lesson and links the learning between the lessons as a conceptual storyline. At the end of each lesson, students make connections to their understanding of the investigative phenomenon (and to the anchoring phenomenon if appropriate).

The investigative phenomena for the learning sequence are various Rube Goldberg® machines in which objects move. Students figure out these phenomena by:

Science and Engineering Practices (SEPs)

Asking Questions and Defining Problems

- Ask questions about what would happen if a variable is changed.
- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
- Define a simple design problem that can be solved through the development of ~~an object,~~ tool~~, process, or system~~ and includes several criteria for success and constraints on materials, time, or cost.

Developing and Using Models

- Develop a diagram or simple physical prototype to convey a proposed object, tool, ~~or process~~.
- Develop and/or use models to describe and/or predict phenomena.

Planning and Carrying Out Investigations

- Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.
- Make predictions about what would happen if a variable changes.
- Make observations ~~and/or measurements~~ to produce data to serve as the basis for evidence for an explanation of a phenomenon ~~or test a design solution~~.

Analyzing and Interpreting Data

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

Constructing Explanations and Designing Solutions

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

Engaging in Argument from Evidence

- Compare and refine arguments based on an evaluation of the evidence presented.
- Construct and/or support an argument with evidence, data, ~~and/or a model~~.
- Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.

Obtaining, Evaluating, and Communicating Information

- Communicate scientific ~~and/or technical~~ information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.

Disciplinary Core Ideas (DCIs)

PS3.A Definitions of Energy

- The faster a given object is moving the more energy it possesses.
- Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.

PS3.B Conservation of Energy and Energy Transfer

- Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects, ~~or through sound, light, or electrical currents.~~ Energy can be converted from one form to another form.
- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion.
- Energy can also be transferred from place to place by electrical currents which can then be used to locally produce motion, sound, heat or light.

PS3.C Relationship Between Energy and Forces

- When objects collide, the contact forces transfer energy so as to change the objects' motion.

PS3.D Energy in Chemical Processes and Everyday Life

- The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use.

ETS1.A Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria).

Crosscutting Concepts (CCCs)

Patterns

- Similarities and differences in patterns can be used to sort, classify, communicate, ~~and analyze simple rates of change~~ for natural phenomena and designed products.

Cause and Effect

- Cause and effect relationships are routinely identified, tested, and used to explain change.

Systems and System Models

- A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot.
- A system can be described in terms of its components and their interactions.

Energy and Matter

- Energy can be transferred in various ways and between objects.

The following narrative is based on the conceptual flow found at the end of this section.

Lesson 1: What's Going On?

Investigative Phenomenon: In a Tom and Jerry cartoon, objects in a chain reaction move with one initial contact.

This lesson introduces the students to the investigative phenomenon of chain reactions in a mousetrap in a Tom and Jerry cartoon (similar to a Rube Goldberg® machine) as a common experience for their learning. Students use their prior knowledge from kindergarten through third grade about force and motion to observe and describe chain reactions in terms of action (e.g., movement) and how the action occurred (e.g., forces). They explain their observations in terms of their prior knowledge about energy (DCI), cause and effect (CCC), and in how they ask questions (SEP).

Lesson 2: Oops!

Investigative Phenomenon: A Rube Goldberg® machine stalls when the paper roll doesn't knock over the glass.

In this lesson, students investigate a Rube Goldberg® machine (chain reaction) that stalls. Students compare and contrast the sections of the system that work and those that don't in terms of force, energy (as they understand it), collisions, and speed. They learn about systems (CCC) in terms of their components and interactions by investigating (SEP) their section/part of the Rube Goldberg® machine to begin to explore: what is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred? Where does it come from, what does it do, and where does it go? They look for cause and effect relationships (CCC) and patterns (CCC) in the data.

Lesson 3: Collisions and Speed

Investigative Phenomenon: In a Rube Goldberg® machine, moving objects collide with stationary objects.

In this lesson, students use the knowledge gleaned from their observations of energy transfers to describe energy in terms of speed and collisions by noticing patterns (CCC) and cause and effect relationships (CCC) They plan and conduct an investigation(SEP) about the relationship of speed and energy to collisions of objects. Students also construct an explanation using evidence (SEP) from their investigation to support the claim that faster-moving objects have more energy. Finally, they recall the failed Rube Goldberg® machine from Lesson 2: Oops! and propose a solution.

Lesson 3a: Optional Formative Assessment

Investigative Phenomenon: Bowling pins can fall even if the ball doesn't touch them directly.

Use this **optional assessment** if students need support to understand that observations can produce data as evidence, that within a system, moving objects contain energy, that the faster the object moves, the more energy it has, and that energy can be moved from place to place by moving objects. Students conduct an investigation (SEP) to continue their exploration of how energy moves and formally label this movement as energy transfer. Students continue their exploration of how contact forces transfer energy between components within a system (CCC). Students think about the questions from Lesson 2: Oops! What is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred? Where does it come from, what does it do, and where does it go?

Lesson 4: Energy Transformation

Investigative Phenomenon: Energy transfers can be observed in parts of a Rube Goldberg® machine where energy converts its action to movement, sound, electricity.

In this lesson, students test various devices (SEP) that convert an energy source into a different action (e.g. rubbing hands together to produce heat and sound). Students make observations to produce data that they analyze for trends or patterns that they will use as evidence to construct an explanation. They also learn to refine their arguments based on an evaluation of the evidence. They continue to recognize that energy can be transferred in various ways between objects and continue to ponder the system (CCC). They revisit the questions from Lesson 2: Oops! What is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred: Where does it come from, what does it do, and where does it go?

Lesson 5: Do-it-yourself Machines

Identified Problem: Use a Rube Goldberg® machine to solve a classroom problem.

In the last lesson of the unit, students apply their understanding of energy and its transfer/transformation in a design solution (SEP) to meet human needs. Students design a Rube Goldberg® machine that humorously solves a classroom problem (CCC) using the principles of engineering (defining a simple design problem that can be solved by the development of a tool using criteria and constraints; making observations to produce data to serve as the basis to test a design solution; applying scientific ideas and evidence to the design of a prototype tool; and comparing and evaluating solutions based on how well they meet the criteria and constraints of the design). At the end of the lesson, students recognize that a Rube Goldberg® machine is a fun but impractical use of energy. Students link different cards to show energy being used for practical purposes.

Learning Sequence 3-Dimensional Progressions

SEP PROGRESSION	
Asking Questions and Defining Problems	
Lesson 1	Accessing prior knowledge from K–2 (ask questions based on observations to find more information about the natural world), students ask questions that can be answered by an investigation.
Lessons 2 and 3	Students ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
Lesson 4	Students ask questions to plan their investigation. They question what happens when a variable is changed and predict reasonable outcomes based on observed patterns (i.e., cause and effect relationships).

Learning Sequence 3-Dimensional Progressions (continued)

SEP PROGRESSION (continued)	
Asking Questions and Defining Problems (continued)	
Lesson 5	Students define a simple design problem that can be solved through the development of a tool that meets the criteria and constraints for the design.
Developing and Using Models	
Lessons 1 and 2	Students develop and use a model to describe the phenomenon.
Lesson 5	This practice is addressed as a background practice where students develop a simple physical prototype to convey a proposed tool.
Planning and Carrying Out Investigations	
Lesson 3	Students build on their K-2 of conducting an investigation to collaboratively produce data as evidence to support an explanation of a phenomenon. Students continue to build their understanding of the practice including using fair tests in which variables are controlled and the number of trials considered, making predictions about what would happen if a variable changes, and making observations to collect data that can be used as evidence to construct an explanation.
Lesson 4	Students continue to make observations to collect data that can be used as evidence to construct an explanation as to how energy is transferred or transformed.
Lesson 5	Students use their observations to produce data to test a design solution.
Analyzing and Interpreting Data	
Lesson 2	Students represent data pictorially to reveal patterns that indicate relationships.
Lessons 3 and 4	Students analyze and interpret data to make sense of the phenomenon.
Lesson 5	Students use data to evaluate and refine design solutions.
Constructing Explanations and Designing Solutions	
Lesson 3	Students use evidence (observations and patterns) to construct or support their explanations.
Lesson 4	Students use their observations to find trends (patterns) in their data. They use these patterns to construct an explanation about energy transformation.
Lesson 5	Students apply scientific ideas to solve design problems. They use evidence to design a solution to a problem, and they compare solutions based on who well they meet the criteria and constraints of the design solution.

Learning Sequence 3-Dimensional Progressions (continued)

SEP PROGRESSION (continued)	
Engaging in Argument from Evidence	
Lesson 4	This SEP plays a supporting role in constructing an explanation. Students support their argument (claim) with evidence and then compare and refine their argument based on an evaluation of the data presented.
Obtaining, Evaluating, and Communicating Information	
Lesson 4	While this practice is not in the foreground of the learning sequence, it is in the background of most lessons where students are asked to communicate scientific information orally and/or in written format (mostly diagrams and charts). It is specifically addressed in Lesson 4.

DCI PROGRESSION	
Lesson 1	Forces and collisions cause things to move (from K and 3rd grade).
Lesson 2	Energy is present when there are moving objects. Energy has a source and causes an action that we can use. Energy can be moved from place to place by moving objects. Energy transfers in, within, and out of different systems.
Lesson 3	Speed and collisions affect the transfer of energy. The faster an object is moving, the more energy it possesses. When objects collide, the contract forces transfer energy so as to change the object’s motion.
Lesson 3a	This optional lesson reinforces the DCIs from Lessons 2 and 3.
Lesson 4	Energy is present whenever there are moving objects, sound, light, or heat. Energy can be transferred (converted) into different actions. Energy can be transformed from place to place by electric currents to produce motion, sound, heat, or light.
Lesson 5	An “energy machine” can be designed to convert stored energy into a desired form for practical use. The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use. Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of the solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specific criteria for success or how well each takes the constraints into account.

Learning Sequence 3-Dimensional Progressions (continued)

CCC PROGRESSION	
Patterns	
Throughout the learning sequence, students use the same questions to debrief their learning from various explorations. The answers to these questions establish patterns in a variety of ways that can be used as evidence for their explanations.	
Cause and Effect	
Lessons 1 and 2	Students identify causal relationships and use these relationships to explain change.
Lesson 3	Students identify causal relationships, speed and energy, and use these relationships to explain the change (increased speed equals increased energy).
Lesson 4	Students use the crosscutting concept of cause and effect relationships to understand a variety of energy transformations.
Lesson 5	Students test causal relationships as they design their Rube Goldberg® machine and use those relationships to explain change.
Energy and Matter	
Throughout the learning sequence, students focus on the fact that energy can be transferred in various ways and between objects.	
Lesson 1	Students begin to recognize that energy transfer occurs in the Tom and Jerry cartoon.
Lesson 2	Students continue to identify energy transfers in the Rube Goldberg® machine.
Lesson 3	Students use the crosscutting concept of energy and matter to explore the relationship between speed and energy in collisions.
Lesson 4	Students continue to recognize that energy can be transformed in various ways and between objects.
Lesson 5	Students design a Rube Goldberg® machine using this crosscutting concept.
Systems and System Models	
Throughout the learning sequence, students have various experiences with the element “a system can be described in terms of its components and their interactions.”	
Lesson 2	Students are introduced to a system as a group of related parts that make up a whole, and they describe the system in terms of its components and their interactions. These two ideas are carried into Lessons 3, 4 and 5.
Lesson 3	Students describe the system in terms of speed and collisions.
Lesson 4	Students describe various energy transformations in terms of their components and interactions.
Lesson 5	Students describe the system of their own Rube Goldberg® machine.

References

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K–12 Science Education Standards. National Academies Press, Washington, DC.

Grade 4 Chain Reaction: Energy in Motion Conceptual Flow

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Energy is transferred and transformed in everyday activities.

Investigative Phenomena and Identified Problem

Objects in a chain reaction move with one initial contact.	A Rube Goldberg® machine stalls when the paper roll doesn't knock over the glass.	Moving objects collide with stationary objects.	Optional assessment: Bowling pins can fall even if the ball doesn't touch them directly.	Energy in a Rube Goldberg® machine converts its actions to movement, sound, light, electricity.	Use a Rube Goldberg® machine to solve a classroom problem.
PS3.A, PS3.B, PS3.C	PS3.A, PS3.B, PS3.C	PS3.A, PS3.B	PS3.B	PS3.B	PS3.A, PS3.D, ETS1.A
Contact forces can cause chain reactions.	Contact forces cause objects to move; energy is present in moving objects.	When objects collide, energy can be transferred from one object to another.	Energy in moving objects can be transferred through collisions.	Energy is present whenever there are moving objects, sound, light, or heat. Energy can be transformed to produce motion, sound, heat, light, electricity.	"Produce energy" refers to conversion of stored energy into practical use; solutions must consider constraints and criteria.

Asking questions and defining problems

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Constructing explanations and designing solutions

Engaging in argument from evidence

Obtaining, evaluating, and communicating information

Cause and Effect

Energy and Matter

Patterns

Systems and System Models