# **UNIT 1 – Qualitative Models of Energy Storage and Transfer**

# Instructional Goals

**1. View systems and change in terms of interactions and energy storage**

* Develop concept of systems and energy storage modes
  + Emphasis on representations: system boundaries and pie charts to represent energy storage
* Develop basic concept of energy transfer among storage modes –
  + (In later units, the full concepts of working, heating and radiating will be drawn out and more fully developed)
* Develop the concept of conservation
  + Emphasis on representations: system schema, state diagrams, energy pie charts and energy bar charts (note: bar charts can be introduced now or in Units 2-6, as greater need arises for this representation)

**2. Using Representational Tools for Systems and Change**

* Identify and represent systems using a System Schema to represent the objects in a system, objects in the surroundings, and the interactions of objects within a system or between the system and the surroundings.
* Represent changes in energy storage using Energy Pie Charts.
* Represent changes in energy storage and energy transfer using Energy Bar Charts (This can be done in Unit 1 or gradually developed over Units 1-5 and introduced in Unit 6).
* **Represent change over time in a system by representing a succession of states, each with its own bar chart documenting change in energy storage**

**3. Use variable force of spring lab activity to demonstrate energy storage**

* Collecting and representing data

**4. Constructing systems to use or store energy**

* Participating in an engineering design challengeinvolving “wind collection” device, students will construct and use for data collection.
* Units 3, 5, and 6 will revisit this engineering project for further iterations of the Engineering Design cycle introduced here.

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# Overview

The main goal of this unit is to begin engaging students in the Science Practices, and do this early in the course. The Next Generation Science Standards (NGSS) identify 8 key Science Practices, which Modeling Instruction and this Modeling Instruction in Physical Science Curriculum support:

1. Asking questions (for science) and defining problems (for engineering)

2. Developing and using models

3. Planning and carrying out investigations

4. Analyzing and interpreting data

5. Using mathematics and computational thinking

6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information

The materials in Unit 1 will encourage students to engage in these science practices and begin speaking science, beginning with the first activity. Unit 1 begins promoting these practices directly, except for the direct use of mathematics and computational thinking, which will be emphasized in the remaining units starting with Unit 2.

The focus of Unit 1 is to introduce students to the three major themes of the curriculum: Interactions, Energy, and Structure. We do this by starting with an initial study of change, moving into a discussion and definition of Energy, *developing key representational tools* along the way. At the end of Unit 1, students will be prepared to “dive deeper” into the phenomena in Unit 1, further developing their models of the cross-cutting concepts of Interactions, Energy, and Structures (systems).

A robust energy concept is central to an understanding of all science. Although treated as if it is a straightforward and easily defined quantity, energy is notoriously difficult for people to understand, and is often confused or confounded with the concepts of force and power and even speed.

The following six major themes will be introduced and discussed in Unit 1 so that they may be further developed in the Modeling Physical Science Curriculum, in alignment with the Next Generation Science Standards (NGSS):

**I. An Operational Definition of Energy:**

Usually defined simply as “the ability to do work,” a more general and useful definition of Energy is *“the ability to cause a change.”* One reason to use the more general definition is that the term “**work**” is one that is often misunderstood as well. In this unit we will direct student observations to identify changes within systems as a starting point for the energy concept development.

There are two things that can be done with energy—it can be *transferred* and/or it can be *stored*. By identifying what changes during an event or process (i.e., change in motion, position, shape, temperature, etc.), we can identify the means of energy transfer or changes in the way energy is stored.

**II. System Identification:**

The notion of a system is an essential element of understanding the concepts of energy, interactions, and structure. Specifying a system of interest basically defines the spatial bounds within which we will look at change. Attention needs to be paid to what objects are considered part of the “system,” which are considered part of the “surroundings,” and how objects interact either within the system or across system boundaries. Ultimately, system identification begun in Unit 1 will greatly assist our model of energy storage and transfer.

A system may be closed (in other words energy may be transferred from one storage mode to another but it all remains within the system) or open (energy is transferred into or out of the system). The identification of the system and its boundaries is arbitrary, but critical for accurate energy interaction analysis. The larger the system designation, the more energy interactions will be classified as internal energies. If objects in the system interact with the surroundings, external energy transfers in to or out of the system may need to be considered.

**III. Energy Storage:**

Energy is stored in a system as internal energy. This internal energy IS a *property* or *state variable* of the system, due to the microscopic and macroscopic energies of the particles of the system. These energies cannot be measured directly. A *change* in internal energy is all that can be accounted for, since a change in internal energy results in a change in the *state variables* of the system (position, velocity, pressure, temperature, etc.). Stored energy is therefore represented using ∆ notation.

There are two general ways that energy can be stored in a system:

1. Energy can be stored in the *position* (or *configuration* or *arrangement*) of the constituent parts of an object or system of objects, and
2. Energy can be stored in the *motion* of an object or a system of objects, or in the system’s constituent parts.

Examples of energy of position or configuration are the energy of an object suspended above the ground, the energy of a compressed spring, or the energy of a molecule that has its atoms in a particular geometric configuration. These are traditionally referred to as ‘*potential’* energies. In Modeling Instruction, we try to eliminate the use of the word ‘potential’ and focus more on the actual ways in which energy is stored in a system. This is discussed further on in the Teacher Notes.

Examples of the energy of motion would be the energy of an object traveling at some velocity, *v*, or the energy of an object with molecules vibrating or moving at a particular average speed (a measure of this average energy is also known as an object’s “temperature”). These energies of motion are sometimes called *kinetic* or *molecular kinetic* energy. An object’s temperature (a measure of its average molecular kinetic energy) is sometimes also called its *thermal energy*.

We use “E-subscript” notation to indicate that all modes of energy storage do just that, store *Energy*. The mode just helps us keep track of how energy is stored. Here are some examples of “E-subscript” notation:

* Energy in gravitational field: Eg
* Energy in springs or “stretchy” things: Eel
* Energy in electric field due to physical state: Eph
* Energy in electric field due to chemical bonding: Ech
* Energy in moving object, Ek
* Energy in a collection of moving particles (as measured by temperature), Eth

It is important to understand that, although we may use different names for energy storage (e.g., kinetic, gravitational, chemical), energy is energy, regardless of the way it is manifested. The names we have for energy storage simply tell us something about how some element of a system’s energy was measured, and allow us to separate a system’s total energy into different categories, so that we can more easily account for *changes* in one category or another.

**IV. Energy Transfer:**

Energy transfer will be addressed in terms students are familiar with during Unit 1. We will encourage students to use terms like “pushing,” “pulling,” “heating up,” “cooling off,” etc. until we have encountered enough phenomena and developed a need to further discuss the terms that will go along with these concepts.

The materials in Units 2-10 will help students develop three major mechanisms to help understand how Energy can be transferred in to or out of a system during changes:

* **Working (*W*)** involves the transfer of energy by external forces acting on an object across some distance. The concept of working is introduced early through concept of ‘pushing’ and pulling. Eventually students will be able to quantify the amount of energy transferred via Working as the product of the component of the input force in the direction of the object’s motion and the distance travelled by the object.
* **Heating (*Q*)** involves the transfer of energy due to differences in temperature. Higher temperature objects in contact with lower temperature objects transfer energy via particle collisions. Eventually students will be able to quantify the amount of energy transferred via Heating using observed temperature changes in the system and developing a concept of ‘heat capacity.’
* **Radiating (*R*)** involves the transfer of energy by photons or electromagnetic waves. Early on, students will observe different ways that waves and light may be involved in changes and energy transfer. Eventually students will be able to examine the relationships between different properties of light and waves and the ability of waves to transfer energy.

These three mechanisms of energy transfer are considered *macroscopic* processes. These transfers are NOT *properties* of the system. They do not represent *changes* in the state of the system (hence we do not use the ∆ notation to describe them). Since they are processes, and not intrinsic in the system, we feel it is better to use the gerund form of each of these words (e.g., heat*ing*, work*ing*, radiat*ing*); otherwise students may come to view *W, Q*, and *R* as a synonym for energy, or as an actual part of the system. For example, we would not want to say that a system possesses "heat". Rather, we would say a high temperature system stores energy and it can transfer that energy to another system through the process of *heating*.

**V. The 1st Law of Thermodynamics, and Conservation of Energy**

According to the Law of Conservation of Energy, the algebraic sum of changes in internal energy in the system must equal the energy transfers across the system boundary. In terms of our energy storage accounts, the total energy change in a system is equal to the sum of any and all internal energy changes:

**∆Esystem = ∆Eg + ∆Eel + ∆Eph + ∆Echem + ∆Ek +∆Eth**

In these materials, we will designate all processes that increase the energy of the system as positive: transferring energy into the system by heating it, working on the system (energy transferred in by forces), etc.

Energy that decreases the energy of the system is designated as negative, such as energy leaving by cooling a system, or working done by a system (energy transferred out by forces).

Thus the 1st Law of Thermodynamics can be stated as:

**∆Esystem = *W* + *Q* + *R***

where **∆Esystem** is the sum of all the changes in a system’s energy storage modes, using the same sign designationas stated above. When connected to the energy transfer mechanisms, this comprehensive statement of the 1st Law of Thermodynamics is sometimes referred to as “The Equation of Everything”:

***W* + *Q* + *R* = ∆Esystem = ∆Eg + ∆Eel + ∆Eph + ∆Echem + ∆Ek +∆Eth**

To use the 1st Law in this form, one must identify the system first, and then determine the appropriate modes of internal energy storage mechanisms which undergo changes, and which energy transfers are involved.

**VI. Representational Tools:**

This unit uses three representational tools, which are listed here according to their increasing levels of complexity. Their use will be explained in detail in a later section:

***1. System Schema and System State diagram:***

* qualitative and simple tool for identifying the objects in a system
* identifies the interactions between objects in the system
* establishes a system boundary
* identifies if interactions are occurring with the surroundings across a system boundary.
* helps in deciding if energy transfers into or out of the system during a change, or if energy transfers take place within the system.
* illustrates the state of a designated system at time *t* (e.g., initial and final)and can be used in a series to visualize change in system state while energy transfer is occurring. State diagrams are most useful in representing change in events where observable motion occurs.

***2. Energy Pie Charts:***

* very qualitative, and relatively limited use - generally for introductory use, especially Modeling units, as post-lab discussion
* introduces the idea of internal energy as a *property* of a system
* introduces the concept of *changes* in internal energy of the system
* stresses the importance of system identification
* introduces the various mechanisms of energy storage
* does not represent energy transfers across system boundary, except for some simple examples of external forces
* represents Conservation of Energy and 1st Law of Thermodynamics
* introduces internal energy as a sum of energies:

∆Esystem = ∆Eg + ∆Eel + ∆Eph + ∆Echem + ∆Ek +∆Eth

***3. Energy Bar Charts and Flow Diagrams (essentially energy system schema)***

* often used in post-lab discussions
* identifies internal energy changes, but also shows means of energy transfer across system boundary
* introduces concept of work as energy transfer across system boundary via external forces
* makes distinction between *changes* in internal energy and energy transfer as a *process.*
* shows how macroscopic energy transfer *W, Q, R* can affect microscopic energy storage ∆Esystem (system’s internal energy)
* introduces 1st law of Thermodynamics: ∆Esystem = *W* + *Q* + *R*
* slightly more quantitative than pie charts
* useful for representing Conservation of Energy and 1st Law of Thermodynamics
* can be used in series to represent change in energy storage modes in a dynamic system
* can be used in conjunction with state diagrams in systems where the event involves observable motion

**NGSS Crosscutting Concepts Addressed in Unit 1:**

|  |  |
| --- | --- |
| **Crosscutting Concept:** | **Specific Example(s):** |
| 1. Patterns | Activity 2,  Worksheets addressing patterns in energy storage |
| 2. Cause and Effect | Activity 1: Observation Stations |
| 4. Systems and System Models | Worksheets (System Schema tool, and system identification) |
| 5. Energy and Matter | Worksheets 2-6 (with supporting whiteboard discussions) |
| 7. Stability and Change | Observation Stations,  Engineering Project |

# Unit 1 Sequence:

1. Activity 1: Observation Stations
2. Worksheet 1 & Reading 1: Defining a “System”
3. Worksheet 2 & Reading 2: Energy & Energy Pie Charts
4. Worksheet 3: More energy pie charts and system schemas
5. Quiz 1
6. Activity 2: Tell an Energy Story
7. Activity 3: (Lab): Exploring Energy Storage in Springs
8. Worksheet 4: Elastic energy storage and transfer
9. Quiz 2

*\*Note: Items 10-13 can be included in Unit 1 or at the start of Unit 6. See Teacher notes for more information*

1. Activity 4 – Observation Stations Revisited: describing energy transfers
2. Discussion / Worksheet 5: Representing Energy Transfers
3. Reading 3: Representing Change with Energy Bar Charts
4. Worksheet 6: Practice Representing Systems and Change

1. Windmill Engineering Design Project (Intro and first Design Cycle)
2. Worksheet 7: Energy in the Engineering Design Project
3. Worksheet 8 (Optional): Extra Practice with Energy Storage
4. Activity 5: Modeling Change Over Time in a System
5. Activity 6: Computationally Modeling Change Over Time in a System
6. Unit Review / The Model So Far
7. Unit Test

# Unit 1 Instructional Notes:

# 1. Activity 1 – Observation Stations

## Purpose(s)

The purpose of this introductory activity is to attune students to getting students to “do science” and start developing their science skills (or NGSS Science Practices) from the start of Unit 1. The Observation Stations will give the students initial experiences to make observations, to learn to specify the “system of interest” when observing some event, to develop skills recording data/information, to begin using scientific language and discourse, and to think about the changes they are observing more deeply.

During the post-lab discussion, students will engage in further discussion regarding describing systems, change, and where/how the **energy** in a system is stored and what evidence they have to support their assertions about energy storage.

And finally, the most significant overarching goal of these Observation Stations is to give students *a large group of shared experiences* that will set up the discussion of energy, not only in Unit 1, but in each Unit to follow in this Modeling Physical Science course. **Think of these stations as a “hub” of student experience for the coming year.** Each new unit will loop back to a station (or stations) that students explored in Unit 1, and dive deeper into the phenomena introduced here in Unit 1.

## Apparatus & Materials

Please see the “Unit 1 Observation Stations Teacher Checklist” for help choosing stations for your classroom. We recommend that you use at least one demonstration/station for each unit that you will teach during the remainder of the school year. The goal of the stations is to try to allow students to experience and discuss interactions and changes that will eventually allow students to discuss ways that energy is stored and transferred, even though they will not fully understand these concepts at this point.

Since concepts of energy will be discussed after this activity, we encourage you to select stations that allow for the discussion of multiple energy storage modes and transfers. You will also want to consider what equipment and materials you already have available, and what you will need to purchase. The electronic Unit 1 folder contains a file of Observation Stations Sheets, with directions pages for each suggested station, and a template you can use to create directions if you add your own stations. Finally, there is a file of Observation Station Student Pages that students can use to record observations during the activity if they do not yet have their own notebooks.

Once you have decided on your stations, set up lab stations so that lab groups will rotate through them. Allow groups to spend ~5 minutes at each station making observations according to the directions provided at each station.

## Pre-lab Discussion

At each Observation Station students will be asked to perform one or more activities and respond to the following three prompts. These stations use a variety of manipulatives. Some stations feature common household items; others use either commercial devices or teacher-produced apparatus. The procedure at each station must be followed as directed and eye protection must be worn at all times! Lab safety policies will be strictly enforced. Students must:

1. Describe **what they did** or the procedure they followed at the station from beginning to end. They should include an accurate description of the items involved as well as actions performed.
2. Describe **what they saw or observed** during this event. They should be careful not to confuse what they saw/observed with what they think is happening. Ask them to make a simple diagram of the system of interest for each station.
3. Describe **what changes** occurred in this event, from beginning to end. Based on their observations and prior knowledge, they should record whatever conclusions they can draw concerning changes in the system during the events at each station.

## Lab Performance Notes

Rotating through the stations will likely take the entire lab period. Monitor student groups for safety and cleanliness as they work.

## Post-lab Results Sharing

You may or may not choose to follow-up this exercise in making observations with a board meeting. If you do, you may wish to assign one station to each group to whiteboard. They should represent their findings, if possible in more than one way, they should be able to support their assertions about the system changes in the events with observable evidence (this might be a good time to talk about how we observe, e.g., see, hear, feel, smell, taste as well as the need to negotiate agreement with other who may have different perceptions). They should be able to clearly articulate their conclusions and any constraints that apply to them.

If you don’t want to take the time to whiteboard these findings at this point, in the next few activities students will draw upon the observations they made at these stations and develop skills at representing their findings, first by making system schemas, and then by representing the each system’s energy storage modes in pie chart form.

Regardless of whether or not your students whiteboard their lab station findings, they must retain their lab notes for this lab as they will be used to complete several follow-up assignments.

2. Worksheet 1 & Reading 1: Defining a “System”

# The first post-lab discussion (model development) focuses on defining systems. Worksheet 1 introduces the students to defining and representing systems using the changes they observed in the Activity 1 Observation Stations. Students will work on identifying objects in the system, and representing interacting objects using a System Schema and State Diagrams. If they do not do the reading before they do the worksheet, let them know that the system schema is a simple diagram that shows how the objects in the system interact with each other, and the State Diagrams are “before” and “after” diagrams of the configuration of objects in the system. Note that there needs to be observable change in position of elements within their system in order for State Diagrams to be useful in analyzing change. If you do the worksheet before the reading, you will want to work through one of the stations with the students (soliciting their feedback and following their lead of course). As students work on analyzing the remaining stations, encourage them to regularly use their observations from the Activity 1 Observation Stations to help them.

# During the Whiteboard Session for this worksheet, try to encourage the students verbalize how or why they are choosing to represent objects and interactions in their System Schemas. Try to encourage the students verbalize how or why they are choosing to represent objects as part of the system, the surroundings, and how/what objects interact.

# Please don’t expect perfect System Schemas and State Diagrams from students at this early stage. Instead, use their likely imperfect representations to get the discussion started! The goal in the early stages of the school year is for these young students to start engaging in scientific dialogue and discourse, supporting their representations and trying to understand the representations of others. As a teacher, try to continue developing your skills of asking probing questions of students, and then deeply *listening* to their responses. This will help you understand their thinking and guide the discussion with further questions. The discussion doesn’t need to lead to a perfect understanding, just an improved one based on their observations and data.

**Reading 1: Defining a “System”**

Reading 1 may be given before or after worksheet 1 depending upon whether or not the teacher wishes to introduce these representations in class and have students read about them afterward (recommended), or complete the reading first and then attempt to employ them in class while working on the Worksheet 1 problems.

*Additional Note on Readability Statistics (taken using Microsoft Word):*

* *Flesch-Kincaid Grade Level: 8.3*

3. Worksheet 2 and Reading 2: Defining and Representing “Energy” (Energy Pie Charts)

# The second post-lab discussion (model development) focuses on developing an operational definition of the term “energy” and then introducing a representational tool for energy storage: the Energy Pie Chart. You may wish to start this discussion as a class, asking student groups to discuss “change” and what causes “change.” The goal of this discussion is to help students recognize that systems undergoing change involve interactions that change their initial state to some other state. This ability to change is what we often refer to as “energy.” An operational definition for energy early in this stage is “the ability to cause a change.” Energy then, is not a thing itself, but a property of the objects in a system. The changes in the Observation Stations can now all be viewed through the lens of changes in *energy*.

# After this discussion, distribute Worksheet 2. Worksheet 2 introduces the students to representing energy storage during the changes they observed in the Activity 1- Observation Stations. Students will work together to identify the changes they observe in the systems, representing their ideas using Pie Charts.

# They should also include State Diagrams where appropriate. This is an opportunity for students to develop some judgment about when a representation is useful and should be included versus when it would not provide any useful information and is therefore unnecessary. Representations are sense-making tools. The State Diagram, in particular, focuses students’ attention on observable changes of position or configuration in a system. If there are no observable changes of position or motion in the system, then State Diagrams provide no new information and there’s no reason for students to take the time to make them.

# If you do the worksheet before the reading, you will want to work through one of the stations with the students (again soliciting their feedback and following their lead).

# As students work on analyzing how systems store energy, let them use their own language at the start. At this point, you can encourage students to use “E-subscript” notation. For example, with the tumble buggy station, they may note that energy is stored in the car’s battery. We could write this as *Ebattery*. The buggy is also moving and has energy of motion, and we could write that as *Emoving*. If students need evidence that moving objects “store” energy, ask them if they remember getting hit with a moving playground ball in Dodgeball or some other suitable example. As students work through the other stations, encourage them to use their System Schemas from Worksheet 1 and their observations from the Activity 1 Observation Stations to help them. They should again include State Diagrams *where applicable*—one for each energy pie.

# Again, please don’t expect perfect Energy Pie Charts from students. As with system schemas, use their likely imperfect representations to get the discussion started! The goal in the early stages of the school year is for these students to start engaging in scientific dialogue and discourse, supporting their representations and trying to understand the representations of others. As a teacher, try to continue developing your skills of asking probing questions of students, and then deeply *listening* to their responses. This will help you understand their thinking and guide the discussion with further questions. The discussion doesn’t need to lead to a perfect understanding, just an improved one based on their observations and data.

# During the Whiteboard session for this worksheet, try to encourage the students verbalize how or why they are choosing to represent objects and interactions in their System Schemas. Encourage students verbalize how or why they are choosing to represent energy storage in the ‘Slices’ of their ‘Energy Pies’ and whether their Energy Pies and State Diagrams are telling the same story about what is happening in their system. Also, be on the lookout for students who may be confusing the way energy is stored with the way energy is transferred. If this comes up in discussion, try to encourage students to use verbs for the transfer of energy (like “pushing” or “pulling”) while encouraging students to look at the state of the system as represented in their State Diagrams to decide how energy storage changes from one state to the next (i.e. storage in motion or in position).

# After discussing all the different ways that energy is stored in these objects, we can now come to consensus on what we call these storage modes. Make a list of all the different energy storage modes students came up with. This list should allow you and the class to find similar methods, and discuss agreed on terms for the energy storage modes. Try to get the students to agree on the following main concepts:

* Energy stored in motion:
  + Energy in moving object, Ek
  + Energy in a collection of moving particles (temp), Eth
* Energy stored in position (or arrangement) of particles:
  + Energy in gravitational field, Eg
  + Energy in springs or “stretchy” things, Eel
  + Energy in electric field due to physical state, Eph
  + Energy in electric field due to chemical bonding, Ech
* Energy stored in the internal system:
  + Internal energy, Eint, is stored in changes to the structure and/or temperature of the system and can no longer be used for change (note: see the notes on Reading 2 below for more discussion of Eint). You may point out the examples of “friction” from the Observation Stations. Again, no need for a full analysis here, ideas of friction and energy transfer will continue to be discussed as we progress from Unit 1!

After discussion, these agreed upon terms will allow us (as a community of students, teachers, and scientists) to have more meaningful discussions of energy, and be able to communicate more unambiguously with one another.

**Reading 2: Constructing Energy Pie Charts**

We recommend Reading 2 be given after worksheet 2, so that students have the chance to use their own language for energy storage before being introduced to the Esubscript notation. But you may have the students complete the reading first and then attempt Worksheet 2 if you wish.

Although the student's initial investigation focused on system "changes" this is where the term "energy" is associated with the "capacity to create change". This is an operational definition that will be developed more fully throughout the course.

A couple of notes on Energy Accounts in Reading 2:

*“What is Eint?”:*

We can think of Energy internal, Eint, as the kinetic and elastic energies of the constituent particles that make up the body in question. So, energy that is “lost” during a change is not exclusively stored in the increased motion of the system’s particles, but also in the changed arrangement of the system. Think of what happens in a collision in which an object undergoes some sort of permanent deformation, like an automobile than collides with a wall. The object may heat up and deform. This helps us understand why in some changes not all of the energy is “easily recoverable”. An auto bumper-fender is not like a spring that stores and then releases energy as it returns to its normal shape.

*“Why aren’t we using the term ‘Potential Energy’? That’s what I learned! It’s in all the books!”*

In Modeling Instruction for high school, we do not use the adjective “potential” for energy storage accounts. This is because the term 'potential' carries everyday meanings that cause misconceptions, for both teachers and students. Also, the term is not needed since the energy storage model used in the Modeling Instruction treatment of energy provides a simple unambiguous way of representing energy.

That said, we understand that teachers and students will have to wrestle with this somewhat, as the term ‘potential’ has been in use for centuries and, like the dinosaurs, will take a while to become completely extinct - especially when textbook authors and some in higher education insist on retaining that term. As teachers, we must deal with this if our textbook use the term ‘potential’. We believe student minds are flexible enough to handle using the clearer ideas and models we are developing over the fuzzier term of ‘potential’ seen in textbooks (in high school or later). Just because a term is traditionally used doesn't mean the word is meaningful. As teachers, we need to provide a clear rationale for using a different convention.

*Additional Note on Readability Statistics (taken using Microsoft Word):*

* *Flesch-Kincaid Grade Level: 9.3*

# 4. Worksheet 3: More energy pie charts and system schemas

# This worksheet integrates System Schema, State Diagram and Energy Pie Chart representations and asks students to use these representational tools to describe some changes (event contexts) *not* observed in the Activity 1 Observation Stations at the start of Unit 1.

# 5: Quiz 1

# 6. Activity 2 - Tell a “Story of Energy”

The handout for this activity has students begin by reading one of the famous excerpts from the Feynman Lectures on the conservation of energy. After students read this “Story of Energy”, instruct them to work in their groups to create their own “Story of Energy.” The summary of their story should fit on one whiteboard, and be large enough to be seen from across the room. After preparing their stories, you can either have groups present to neighboring groups, or each group can take turns presenting to the class as a whole.

**If student groups struggle with coming up with a story or analogy on their own, you may offer some help by suggesting one of the following analogies for energy: money, information, music, etc.** For more background on energy analogies, see Background Reading 1 – Chemistry Energy Reading in the electronic Unit 1 Resources folder. This reading from the Modeling Chemistry curriculum is a great resource for you as the teacher, and you may wish to use or modify this reading for use with your students as well.

As each group prepares and presents their story, try to engage in probing questions and discussions about how the energy is stored, transferred, and conserved. Their stories are likely not perfect at this point, we just want students to engage in the thought of energy transfer and conservation. Initiating the discussion and ideas here will allow us to revisit the concepts of energy transfer and conservation as we proceed through the remaining units.

An optional worksheet about the Feynman reading is also included in the Unit 1 Resources folder if you feel your students need more reinforcement with the Feynman reading.

# 7. Activity 3 (Lab): Exploring Energy Storage with Springs

## Purpose

This lab allows students to see and measure energy stored in springs. By collecting, organizing and representing the data they collect, students can begin to quantify energy stored, yet still in a qualitative way. This is an opportunity to discuss measurement precision and accuracy, and simple graphical methods. \*Teacher’s Note: a full analysis of slope and intercept will NOT be done in this unit.

## Apparatus

Ring stand, spring, ruler, paper clip and 5 or 6 identical large washers for each group

## Pre-lab discussion: Storing energy in a spring

Suspend the spring from the ring stand, bend the paper clip so that it can act as a mass hanger and hang it from the bottom of the spring. One by one place 3 or 4 washers on the mass hanger and invite the students to observe. Let them know that for all practical purposes, the washers are identical in weight (the difference is too small for them to measure with a triple beam balance). Ask them what they observe and record everybody’s observations on the board. If they make assertions like “energy is being stored in the spring” ask them how they know (this is not an observation, it is an inference) and when they say that they know because the spring is stretching, record that on the board as their observation. At some point, you may need to ask them what it is about what they are observing that they can measure or count. They should come to the consensus that they can measure the length of the spring and count the number of weights. At this point you want to distill the driving question that this part of the lab will address: what is the relationship between the energy stored in a spring and the length the spring is stretched?

As students conduct the lab, remember that we are helping them build science skills early on. Students are being asked to collect and organize data, and represent the data graphically, and to communicate with one another regarding their results. We are building these NGSS-based skills early, but keeping them qualitative at this point. While it may be tempting to jump into discussions of slopes, intercepts, etc. at this point, we advise waiting on those discussions until *after* Unit 1, and for now keep students working on the basics of practicing and speaking science.

Caution the students that these springs are delicate and expensive and must not be overstretched. Test the springs beforehand to determine how many washers they can safely support with overstressing them. Suggest that they discuss within their lab groups as they arrive at a procedure for answering this question, how many measurements they will need to take. How much data is enough? You may also wish to discuss with them how to measure the stretch of the spring (e.g., they need to understand that it’s the length of the coils that changes when weight is added, not the length of the loops at the top and bottom of the spring or the length of the paper clip) or you may decide to leave that choice to emerge in the small group discussions as they decide on a procedure their experiment.

**Lab performance notes**

Monitor students as they collect and record data, reminding them to practice specific observations and organized data recording. After collecting data, they may or may not represent their findings in a graph with labeled axes (teacher’s choice), draw a system schema, construct Energy Pie Charts, etc. If they make a graph they should draw a best fit line (do not let them get away with a dot-to-dot line connecting their data points.) You may choose to wait and talk about this during the board meeting, but if you do, make sure that at least some of the lab groups have made a best fit line so you can talk about how it’s a useful tool for making predictions. If students plot a point at the origin, be sure to ask them what this means and if this is really an appropriate data point! (they will *not* be using springs of zero length!).

## Post-Lab discussion

Students should find that number of weights is proportional to the change in length of the spring. Ask students to discuss the meaning of their graphs and/or other representations. They should be able to draw some conclusion about the energy stored in the spring. It is *NOT* important to get into a discussion about slopes, intercepts, or the spring constant at this point.

Students should now be ready for a qualitative discussion of the elastic energy, Eel, stored in the spring. A pie chart analysis of the situation as the spring is stretched shows the pies getting larger with each stretch, indicating more and more energy being stored with each increase in weight. A state diagram analysis should show not only the position of the suspended mass at each point that a measurement is taken, but also the state of the spring, which is changing in length. Help students connect their pie charts to the features of their graphs (i.e. the area of the graph at different points). We are trying to help students connect the data they are collecting and the graphs they are making to the Systems & Energy Model we are building.

# 8. Worksheet 4: Elastic Energy Storage

Worksheet 4 provides students with practice applying their energy models and representations (including System Schemas, State Diagrams and Energy Pie Charts), using scenarios related to the storage of elastic energy, Eel.

One suggested way to use this worksheet is to have each group of students whiteboard just one of the problems, including a System Schema, State Diagram and Energy Pie Chart analysis for their assigned scenario / problem. Then have a Whiteboard Meeting where each group shares their different problems. This may be more beneficial than having every student do every problem with every representation.

Emphasize student-to-student discourse during discussion and/or whiteboarding. The intersection of student thinking around multiple representations is fertile ground for classroom discourse. And as a teacher, remember that there is no one right way to use each of these resources or representations. What you use needs to fit with your “teacher style,” the time available, and the needs of your students. Try to emphasize what you think is best for your class is in terms of conceptual coherence.

# 9: Quiz 2

Quiz 2 will provide formative assessment on student use of System Schemas and Energy Pie Charts. A second version of Quiz 2 is in the electronic resources if you choose to continue with Energy Bar Charts (optional items 10-13).

# *Items 10-13: Optional Unit 1 Addition*

# *Energy Transfers & Energy Bar Charts*

The concept of energy transfer may and should come up in Unit 1. However, in Unit 1, we talk more about the ways that energy storage changes as a system changes, without developing a full model of energy transfer. In Modeling Instruction, we generally take this more gradual approach, only introducing new tools or models as need arises. So the discussion of Energy transfer will again naturally arise, and deserve more attention during and after Units 4 & 5 (with the introduction of the force model that will allow us to go from describing energy transfer via “pushing” and “pulling” as forces transferring energy via Working, W). If you wish to stay with the more gradual approach, ideas for energy transfer and Energy Bar Charts can be seeded in Units 2-5, and Unit 6 will begin with the following optional sequence (see Unit 6 Teacher Notes for Reference)

If your students were exposed to Energy & the use of Energy Bar Charts in Middles School Modeling science, or you wish to include Energy Bar Charts in Unit 1, you can insert the following sequence somewhere before or after Quiz 2.

# 10. Activity 4 – Observation Stations Revisited: describing energy *transfers*

## Purpose

Set up the same lab stations you used in Unit Activity 1 Observation Stations (any lab worth doing, is worth doing over). We will now discuss our “Observation Stations,” this time paying even closer attention to how energy storage changes over time, and how energy is transferred during changes.

## Apparatus

Same apparatus/stations as in Activity 1 Observation Stations.

## Pre-lab discussion

Students should use, or at least refer to, their original lab notes from Unit 1 Observation Stations Activity, adding observations about how the amount of energy stored in each of the various storage modes ***changes*** during their observation of the event at each station. Have them review their Energy Pie Charts and State Diagrams from Unit 1, Worksheet 2 thinking about how energy is stored at multiple time points: at the beginning, at one or more points during the event and at the end. Then students should be directed to think about how (mechanisms and processes) energy *transfers* are occurring either within the system or between the system and the surroundings.

## Lab performance notes

This will be the 2nd time students have observed these changes, so they should not need as much guidance. Reinforce safety concerns, however!

## Post-Lab discussion

You may wish to forgo an immediate whiteboard meeting following this activity, as there will be worksheets that follow-up on the observations they made. If you do decide to take time for a board meeting, focus attention of how the energy stored at each time point at a station changes from one time to the next, and encourage them to develop explanations of *the process that mediated this change*. We want students discussing what processes occurred that allowed energy to be transferred into, out of, or within the system. This discussion should nicely set up the next reading and two worksheets, which will be developing the energy transfer concept and adding energy bar charts to the students’ representation toolkit.

11. Discussion / Worksheet 5: Representing Energy Transfers

# **Pre-Worksheet Discussion:**

# You will want to work through one of the stations with the students (eliciting their feedback and following their lead of course). When using the Energy Flow diagram to show arrows in or out, allow students to describe this transfer using any action verb they think is appropriate, **encouraging them to use the –ing ending for their verbs** (to emphasize the action of the energy transfer). The common terms we use for energy transfer will be developed after we whiteboard the results.

# **Worksheet 5:**

# Worksheet introduces the use of energy bar charts, using the activities from the Activity 1 Observation Stations. As students work on analyzing the remaining stations, encourage them to regularly use their observations from the Activity 1 Observation Stations to help them construct their Bar Charts and Energy Flow Diagrams. The inclusion of State Diagrams provide a bridging representation between Energy Pies and Energy Bar Charts.

# Reminder, don’t expect perfect answers, work to promote discussion and consensus. Continue working on your skills of asking probing questions of students, and deeply listening to their responses. This will continue to help you understand their thinking and guide the discussion with further questions.

# **Worksheet 5 Whiteboarding Notes – Defining terms for energy transfer**

# After whiteboarding Worksheet 1 and discussing all the different ways that energy can be transferred in or between systems, we can now come to consensus on what to call these mechanisms or processes of energy transfer (remember we want to emphasize that these are actions of energy transfer). Make a list of all the different energy transfer mechanisms students came up with. This list should allow you and the class to find similar methods, and discuss agreed on terms for the energy transfer mechanisms. Try to get the students to agree on the following main concepts:

* **Working (*W*)** involves the transfer of energy by external forces acting on an object across some distance. The concept of working is introduced early through concept of ‘pushing’ and pulling. [Note: the following activities in Unit 6 will help students quantify the amount of energy transferred via Working as the product of the input force and the distance travelled by the object.]
* **Heating (*Q*)** involves the transfer of energy due to differences in temperature. Higher temperature objects in contact with lower temperature objects transfer energy via particle collisions. [Note: in Unit 7, students will develop the relationship between the amount of energy transferred via Heating using observed temperature changes in the system and developing a concept of ‘heat capacity.’]
* **Radiating (*R*)** involves the transfer of energy by photons or electromagnetic waves. In the Observation Stations, students have observed different ways that waves and light may be involved in changes and energy transfer. [Note: in Unit 10, students will be able to examine the relationships between different properties of light and waves and the ability of waves to transfer energy.]

12. Reading 3: Representing Change with Energy Bar Charts

# Reading 3 follows this discussion and emphasizes the new representation tool we wish to introduce and discuss - the Energy Bar Chart (EBC). EBC’s will help students more quantitatively represent energy storage and transfer, and diagram how energy flows into or out of a system during a change.

# This reading may be given before or after Worksheet 5, depending upon whether or not the teacher wishes to introduce these representations in class and have students read about them afterward, or read first and then attempt to employ them in class while working on the Worksheet 1 problems.

*Additional Note on Readability Statistics (taken using Microsoft Word):*

Flesch-Kincaid Grade Level: 9.5

# 13. Worksheet 6: Practice Representing Systems and Change

This worksheet gives students practice in system definition and energy storage analysis, using energy pie charts, state diagrams and energy bar charts as a qualitative means of analysis.

When discussing WS6, the analogy of money is helpful to clarify the ideas of energy transfer and storage, as opposed to different forms of energy. Money can be "stored" in many ways - a wallet, a checking account, an IRA, etc., but it is still all money. Only the way it's stored has changed. (See Activity 2 – Telling an Energy Story

A second version of “Quiz 2” including Energy Bar Charts could also be used to assess student learning.

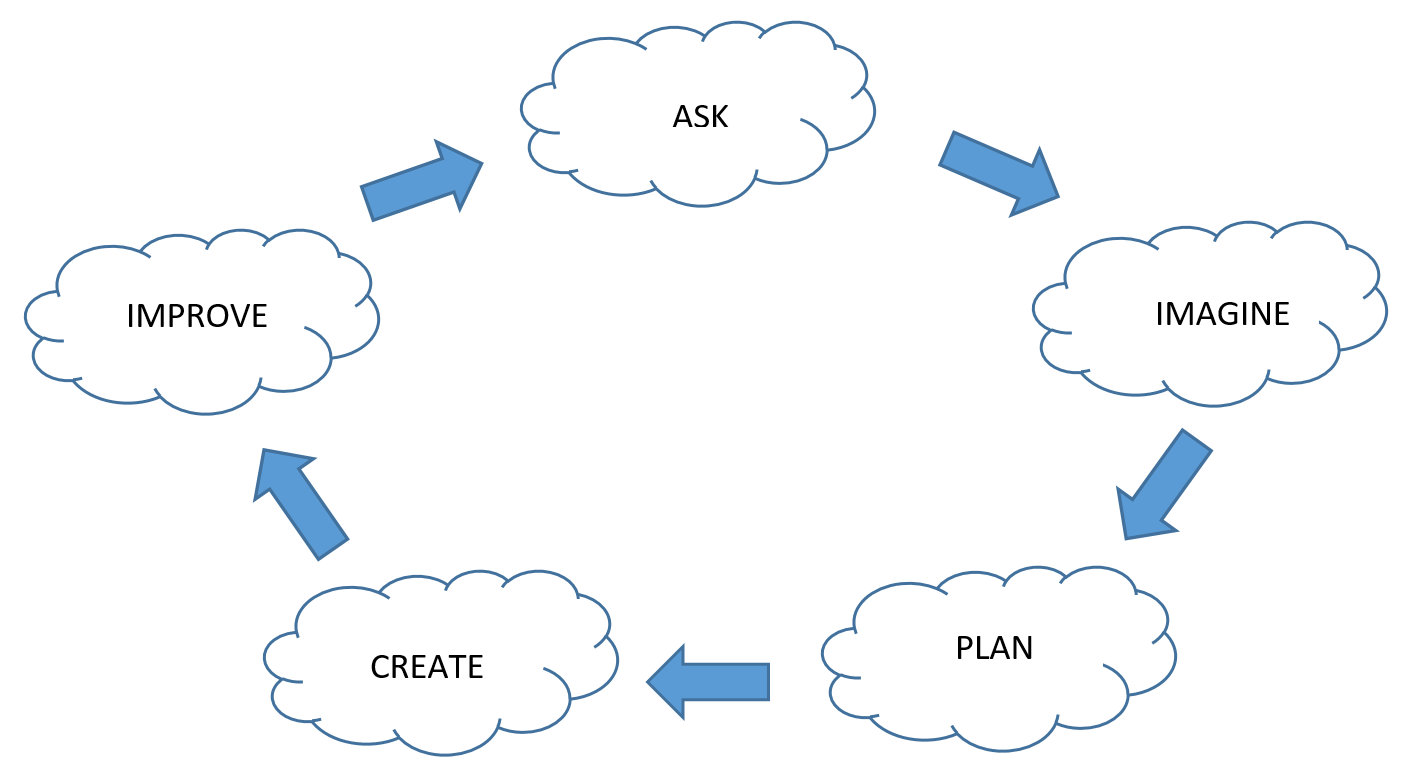
# 14. Windmill Engineering Design Project (Introduction to the Engineering Design Cycle)

## Purpose

Now that students have conceptual models of systems, energy storage and transfer, they can apply these models to design as a system for transferring energy. The central problem for this engineering project is a water delivery system powered by wind (modeled in the classroom by an electric fan.) Each student will be provided with identical materials from which they will be tasked with using the steps of the Engineering Design Cycle to eventually build a prototype. This will be a first opportunity to experience the engineering design cycle (represented below). In each of the units that follow, students will have the chance to do additional iterations of the Design Cycle. This will encourage the iterative nature of the Design Cycle, and that we often have to re-define the problem or discover new ones as we brainstorm, design, and build.

The stages of the design cycle are often referred to by different names, even among different fields of engineering. Please use whatever language you are comfortable with, as long as it fits the spirit of the cycle.

Here is a sample representation of the 5 basic steps of the Engineering Design Cycle:



## Introduction/Motivation

To provide the human context for this Engineering Design Project, instruct students that their goal is to develop a device that will allow them to harness energy from a renewable energy source, the wind. You may wish to show students some images of different windmills from different historical contexts or use contexts. Here are some links to images that are available for use through Creative Commons licensing (a way to copyright, but allow “open” use, more information available at <https://creativecommons.org/> ):

* <https://commons.wikimedia.org/wiki/File:Halnaker_Windmill,_East_Sussex,_UK_-_A26566.jpg>
* <https://commons.wikimedia.org/wiki/File:Water_Pumping_Windmill.jpg>
* <https://www.flickr.com/photos/ipjmike/410780740>

If you wish, you can let students know that eventually we want the windmills to lift small “buckets” (cups) of water. We will begin in this unit by focusing on designing a working windmill turbine.

## Apparatus

The windmills will be powered by a desk or tower fan in the classroom.

Each student group should receive a bag or set of materials containing the following:

* 1 cork
* 5 skewers (wooden barbecue skewers)
* 1 straw
* 1 sheet of card stock
* Masking tape
* Other “found” objects from the classroom or “recycled” objects may be used upon approval (e.g., paper, pencils, empty soda cans or bottles, styrofoam containers or the like).

## Problem Definition: Ask & Imagine

The initial goal of the project is to design a working windmill. This is intentionally vague so that students will need to discuss:

* what the device / the design must accomplish
* what they may use to build it
* what other limitations may be present (time, materials, size/dimensions, efficiency, etc.),
* what documentation is required throughout the process.

Students should sketch out their design and present it to you for approval before they may begin building. They should test what they build, and revise after testing to optimize their design. Discuss safety (handling a hot glue gun, cutting with a hacksaw blade etc.).

## Problem Solving: Plan, Create, and Evaluate prototype(s)

Students must design first and then build. Have them draw a neat, clearly labeled plan for their device that they must bring to you for approval before they begin to build. Examine their drawing to make sure they have stayed within specified parameters. Once you approve their plan they may begin building their prototype. When they are ready to test, they should call for an inspection. After you have inspected their device prototype they may proceed with testing. They should collect data on their test and brainstorm ways to improve on their design. They can then modify their plans, seek re-approval, and then rebuild and test again. They may do as many design cycles as they have time for, but you should set a hard deadline after which their device cannot be altered any further. They must document the entire process!

## Discussion

# Instead of a board meeting following this activity, allow the students to do a “poster session” (or gallery walk). They should present their design (on a whiteboard) in all its iterations, demonstrate their device, and describe the rationale for the optimization strategies they chose. They should be able to describe their design in terms of systems, changes, and energy storage and transfer.

When students have seen all the designs discuss what makes one design better than another: does it spin faster, is it smaller or lighter weight, does it use the least materials? Economics are an important consideration in engineering also.

When finished, if possible their prototypes should be stored for future use. The students will be returning to this project again during Units 3 and 6 to encounter new project engineering goals and complete additional Engineering Design Cycles.

# 15. Worksheet 7: Engineering Design Project Reflections

*Note*: There are two versions for worksheet 7, one with energy pie charts and one with energy bar charts. Use the version depending on the path you took, or you can allow students to use the representation they prefer.

Worksheet 7 asks students to analyze and reflect on their engineering project experience by constructing System Schemas, identifying energy storage modes, and constructing energy pie charts and state diagrams for the prototypes they built. They are also asked in question 3 to reflect on the essential tasks of the engineering design project during this first iteration. Teachers are encouraged to go back to these reflective questions as students revisit this engineering project at the end of later units in the Modeling Physical Science curriculum.

# 16. Worksheet 8 (Optional): Extra Practice with Energy Storage.

*Note*: There are two versions for worksheet 8, one with energy pie charts and one with energy bar charts. Use the version depending on the path you took, or you can allow students to use the representation they prefer.

Worksheet 8 is an optional worksheet you can use to help students review their energy representations (System Schemas, State Diagrams and Energy Bar Charts and Energy Pie Charts)

with some additional scenarios.

# 17. Activity 5: Modeling Change Over Time in a System

Up till now, with a very few exceptions, we have represented change in a system during an event by illustrating the initial and final state of the system. In fact we have paid particular attention to the state in systems where the position or configuration of objects in the system is changing. These “snapshots” of the system at the beginning and end of an event provide only limited information about the change that occurred during the event. Did the change proceed at a constant rate? Were there other increases or decreases in energy storage accounts during the event that don’t show up in the two states we have chosen to illustrate? Consider an event in which I drop a basketball. It will bounce up and down a number of times before it comes to rest on the ground. To thoroughly represent the change that happens in this event we need to show multiple states:

In this activity students will create a flipbook, illustrating change through time by representing multiple states during an event involving change in position of an object.

Introduce the activity by dropping a basketball. Have students look at the ball in your hand and then close their eyes and keep them closed until the ball has finished bouncing and come to rest on the floor. (Those two looks constitute their ‘initial’ and ‘final’ snapshots.) Have them make a state diagram of the initial and final states that they observed. Ask them what the pie charts and/or bar charts for these states would look like.

Now repeat the ball drop, but this time tell them to blink their eyes rapidly while watching the ball. Each blink represents a separate “snapshot” of the state of the system. Have them quickly sketch in their notes this series of state diagrams, and then ask them to imagine what they would see if they put each diagram on a separate page in their notebook and then flipped through it—it would create a simple a motion picture of the event.

Challenge them to make a flip book. For each state they will create an energy pie, an energy bar graph and a state diagram. You can have them do the basketball example illustrated above, or you can let them be creative and allow them to come up an event of their own choosing. It should be a simple system in which energy is conserved. When they are finished ask them to add the general mathematical expression for each of their state diagrams: the sum of the energies stored equals the total energy in the system in each state (e.g., ∆E = Eg + Ek). This may require some coaching. Ultimately they should see that *the same mathematical expression describes each state diagram* because in the system they have chosen *energy is conserved*.

The goal of this exercise is for students to see that *a single mathematical expression*, which we will be referring to as a *function* in the following units, can describe many states. You may wish to arrive at this realization in the course of a whiteboard discussion or you may want to choose one student’s flipbook as an exemplar for a whole class discussion

It is time-consuming to construct multiple state diagrams and bar graphs or pies for every event in order to have a comprehensive picture of the event. The existence of this single mathematical expression that describes every state suggests that there may be a way “automate” the process of creating multiple representations of dynamic systems. Which leads us to…Activity 6.

# 18. Activity 6: Computationally Modeling Change Over Time in a System

In this activity students will have their first exposure to computational modeling with Pyret. Prior to class you will want to test this yourself to make sure the simulation loads and runs on student computers.

They will experiment with the simulation found here:

Student Code: <https://tinyurl.com/ybshgrfy>

Background Code:

<https://code.pyret.org/editor#share=1GpZ4oOzY05Q7jBj_AgO-kUF3209V89xO&v=9df6222>

In the spirit of the apprenticeship model of learning (i.e., “see it, try it, do it”) students will be able to **see** computational modeling by running a simulation for a dropped basketball (which they saw in the previous activity) for which the code has already been written, examine the simulation and an output table of height vs. “tick”(as in the “tick” of a clock). Then they will **try** the computational model—they will have a chance to explore the model by changing two of the parameters and observing how the simulation changes. They will look at a table of values that the program outputs and see how it changes when they change the values of constants.

In the discussion that follows this activity, the students should arrive at an understanding of “tick” as an instant in time. For each tick the program tells the computer to render an image that is essentially a “state diagram” of the system (just as students did manually with their flipbooks). The difference here is that the computer is able to do this quickly…it produces 30 images a second! Encourage them to look at the difference in position from tick to tick—they should see a pattern of decreasing change when the ball is going up and increasing change as the ball is going down. This is the beginning of a shift in students’ mathematical thinking from a parametric view of change to a differential view of change. It is worth taking a few minutes to explore this pattern of differences.

This computational model represents an additional strategy for representing their energy model. Since this unit is a qualitative treatment of energy, we will not go further in our exploration of computational modeling at present. We will model motion and forces quantitatively in coming units and students will learn how to construct the functions that govern their computational models.

# 19: Unit Review / the Model So Far…

At the close of the unit, you may wish to conduct a “Unit Review.” While you are free to conduct reviews as you see fit, in Modeling Instruction, we recommend using an approach called “The Model so Far…”

The modeling approach requires students to develop and use conceptual models to predict and explain the behavior of matter. As more complex behaviors are observed, it stands to reason that models will need to be modified.

At the end of each unit, as a means of preparing for the test, students should review the model they have constructed and refined throughout the unit. This can be done as a homework assignment that they discuss in small groups the next day. Each group can whiteboard their “model so far” (i.e., the key elements operations, relations and rules of the model, how the model is represented and the class can develop a consensus. model To keep them organized and to allow them to see the progression of the models used in the class, the handout "The Model so Far . . ." may be used. This handout can be given to students after the discussion of Unit 1's model and they should write a short paragraph detailing the characteristics of the model (this should be accompanied by representations of the model they used during the unit). Students should keep this handout and add to it at the end of every unit.

For Unit 1 specifically, students should be able to define a system, represent the system at different states, recognize that changes in systems usually involve changes in energy storage and transfer. Students should be able to specify the different ways energy is stored and transferred, identify when energy is conserved (i.e. energy does not move across the system boundary during the event) and should be able to identify and use the main representational tools developed (System Schemas, State Diagrams, Energy Pie Charts, Energy Bar Charts). Their understanding of energy storage and transfer will not be complete, but we are developing a preliminary version of one of the three overarching Models that we will explore in physical science: Energy, Systems and Interactions, and Structure of Matter.

# 20: Unit Test

*Note*: There are two versions for the Unit Test, one with energy pie charts and one including some energy bar charts. Use the version depending on the path you took, or you can edit the versions so students can use the representation they prefer.