PHYSICS AND INVENTIONS
Discovering Physics, Kinetic Sculptures, and Simple Machines

Overview
In this unit students work as engineering design teams to create Rube Goldberg machines. A Rube Goldberg machine is a series of interconnected simple machines that operate without intervention to accomplish a simple task. Prior to the project students construct concepts of physics in various inquiry-based classroom segments based on the idea that students already know much of the laws of physics through riding bicycles, swinging on swings, playing on teeter totters, etc. Students view films of model Rube Goldberg machines and discuss and query the nature of the machines as works of art vs. mechanical devices that provide a function. For the design of their machines students apply the engineer's problem solving cycle, and learn that mistakes are not failures, but opportunities for learning through careful observation and analysis.

Theme Questions
- What is physics?
- What is art?
- How are elements of the physical world (matter and energy) connected?

Big Ideas
- Systems are only as strong as their individual parts.
- System success depends on very delicate relationships between the individual parts.
- The success of a Rube Goldberg machine depends on the same rules for success in Silent Squares.
- If your machine does not work, or mistakes are made, these are not failures, but important opportunities for learning.
- The "laws" of physics can be constructed by carefully observing and thinking through relationships of dependency—"what depends on what."
- Physics is fun.

Learning Outcomes:

Students will
- **Gain an introductory and conceptual awareness of various concepts in the study of physics:** Newton's Second Law (F=ma), The First Law of Thermodynamics (Law of conservation of energy), potential energy, kinetic energy, torque, and equilibrium.
- **Understand interdependence** and the role of individual parts over broad scales of measurement in the success of a whole system.
- **Improve their cooperative group work skills**
- **Enhance creative problem solving skills** through application of the "Engineer's Problem Solving Cycle."
- **Gain an expanded awareness of the meaning of art, and the interrelationship between art and science.**

- **Appreciate and gain confidence in the power of their own ideas and creative potential**
- **Discover that working with the science of physics is *fun.***

Activity Sequence

1. Silent Squares
Begin the unit with Silent Squares (See "Silent Squares teacher notes.) The debrief considers interdependence as a key element for any group to be successful—that any action affects the outcome—"success"—of the entire group, or system. This is a primary component of a Rube Goldberg machine, that failure of any single component dooms the entire machine to failure. All parts are essential.

2. Foundational Knowledge Introduction: Constructing the Laws of Physics
This segment is necessary to establish basic physics principles and terminology. It is delivered in an inquiry fashion with the class, culminating in a teeter totter experiment with students. The key idea is that students actually already know the laws of physics, they just don't know they know them!

<u>Follow this Inquiry:</u>
(Take the liberty to discuss openly at junctures where questions are posed.)

Energy--Potential, Kinetic, Conservation
Hello there—today we're going to explore the science of physics. Does anyone know what physics is? Its actually just the way things work, and how this stuff called "energy" and "matter" relate to each other. What is energy?—light, heat, motion, radiation, radio waves, and more. What is matter? That is stuff, things, objects, and so on. We couldn't have ANY of the cool technology in our lives without knowing physics—this building wouldn't be able to stand if the architects didn't know physics. Probably the most important law of physics is the Law of Conservation of Energy (First law of thermodynamics). This states that "energy is never created or destroyed, it only transforms." This means that the energy just changes form into something else. This also true for matter (stuff). That's kind of wild if you think about it, but actually it makes sense. What happens to a piece of wood when you burn it? It sort of disappears, but it changes. What does it change into?—ashes, heat energy, smoke (gases), light energy and soot.

Now let's look at this a different way. How many of you have ever ridden a bicycle? Okay, of course you have. Look at this drawing, (hill with a bicyclist at the bottom). If you want to ride to the top of the hill, does it take a lot of energy? Of course it does, you need to eat a good lunch, and that sandwich gets TRANSFORMED into energy for you. By the time you get to the top, what happened to all that energy? Where did it go? We say we USED UP the energy, but actually it doesn't go away, as we know, it turns into something else. What did it turn into? Well, think about it, what did you get in return for you ride up the hill? YOU'RE ON THE TOP OF THE HILL!! You can coast down the other side! So the energy you put into got turned into your height on the hill, and as you sit on the top you have **POTENTIAL ENERGY (PE)**. And how can we measure the potential energy? Well you have to ask yourself, what does it depend on? What does the amount of energy I have to put out to get to the top of a hill depend on? Another way to think of it is, what will make me more tired? (Let students list the possibilities). Certainly if I go HIGHER it will take more energy, and if I WEIGH more it will take more energy, so that's it, PE is measured by the height of the object times how much it weighs. But there's another thing —it depends on the force of gravity. As we know, it wouldn't take as much energy to pedal up the same hill on the moon, which has less gravity.

Now what happens when we coast down the other side of the hill? When we get to the bottom what happened to our PE? It's gone, isn't it? We no longer have height, but the energy didn't disappear--what did it turn into? Again, ask yourself, what do you have now at the bottom of hill that you didn't have at the top? You have SPEED!! That's right, and speed energy is called **KINETIC ENERGY (KE).** And because of the law of conservation of energy, we know that the PE must be the same as the KE, or PE=KE. Later on when you study physics more in school you'll learn about equations that express these thing, and you can calculate all sorts of cool things, like how fast you'll be going at the bottom of the hill.

Now there's another thing to think about. What would happen it you ran into a wall when you were moving really fast at the bottom of the hill? Of course that wouldn't be too fun, but when you hit the wall you will hit with some FORCE. What will that force depend on? Well, if you were riding a big motorcycle instead of your bike, would you hit with more force? Of course you would. And what is the difference between the motorcycle and your bike? The motorcycle WEIGHS more. In physics we say it has more MASS. So that's easy, but what else will the force depend on? How fast you are going—your SPEED. So the force depend on these two things, and if either one of them is bigger or less, it will make the force bigger or less. This is called a direct relationship. So there is actually a way we can express this with math. In physics, the speed we were just talking about is actually called ACCELERATION in this case. So the important thing to remember is, that **the force that an object hits another object with depends on its speed (acceleration) and its weight (mass).** This can be very useful to know when you are trying to make your Rube Goldberg machine work. If you let F stand for force, m stand for mass, and "a" stand for acceleration, there is a formula for this: F=ma. What we just created is a very important law of physics created hundreds of year ago by one of the most famous physicists, Sir Isaac Newton. We just call him Newton. This is Newton's Second Law.

Ok, there is one last law of physics we can create by just thinking through it. See this door over here? How many of you have every walked through a door. Just kidding, of course you all have—that's what makes you physicists, and you just don't know it! Let's do a little experiment. I am going to open the door in two different ways, and I want you to predict which way will require more force, more muscle power. The first way is pushing right here (1 foot from the hinge) and the second way is pushing here at the doorknob. How many of you think the first way will take more force? How many of you think the second way will take more force? (The majority of the class will likely choose the first way). See? You're right! You understand the concept of **TORQUE.** Torque is like rotational force, or I sometimes like to call it the "amount of turniness" around a pivot, like a wheel, or a hinge, or even a teeter-totter. So what does the torque depend on? Clearly it depends on how far away from the hinge or pivot we are. And if I push harder, with more force, would it make the door open more, with more torque? Yes it will. So torque is measured by two things: the distance from the pivot, (often call a "fulcrum") and the amount of force. A math expression for that is Torque=force x distance or T=f x d, or T=fd.

Experiment: How much does the teacher weigh?

Let's use the torque formula to calculate my weight—do you think we can? How much do you think I weigh? (The class makes a list of guesses). Ok, lets use this plank and see how close you are…

Materials: a 10 foot 2x6 plank and a block of wood or equivalent about 1' x 6"

Process:

- Center the board with the block in the middle creating a teeter totter
- Choose the lightest student in the class
- Reveal the weight of the teacher
- Student and teacher stand on each end of board. At this point the student will be up and the teacher will be down.
- Ask students: "who needs to walk toward the fulcrum to create equilibrium?"
- Discuss responses, make
- Teacher walks slowly inward until the board balances.
- The distance from the center of the foot to the fulcrum is measured for both the teacher and the student.
- An equation is set up and solved for the student's weight.

3.   Example Rube Goldberg Machine

View the film, "The Way Things Go," (a 30 minute "kinetic sculpture" that highly resembles a Rube Goldberg machine). Follow with a discussion of the film's meaning, along with recalling how it demonstrated the law of energy conservation, KE, PE and Newton's 2nd law. The Rube Goldberg machine in the film does not accomplish a task, but simply ends in a foggy blur. Questions: Is the film a piece of art? What was the intention of the filmmakers? Is there a message? These questions are discussed and debated. A final possible message is considered: "The journey is more important than the destination—learn to gain satisfaction from what you have vs. what you might some day have." Sometimes students bring up the idea of death, that if the law of conservation of energy is true, it implies that we must transform to some different realm when we die.

Film debrief prompts for discussion:

- Was the film art?
- What is art?
- What kinds of "arts" are there?
- What is the function of art in society?
- Has it always been that way?
- What does art do for individuals?
- What is the difference between entertainment and art?
- Should art ever be censored?

- Is mathematics art? --Can it be?
- What is the difference between creativity and art?

4. Designing and Building Machines

Step 1: Make junk list for material to build machines

Brainstorm of a list of junk that students can bring from home. They should all have their own copy of the list put on the board. Below is a sample list:

Sample Materials List For Machines

Cardboard tubes—from toilet paper rolls, paper towels, wrapping paper, etc. Marbles Balls, all kinds, bouncy, ping pong, etc. Dominoes Balloons String Masking tape and duct tape	Small scrap lumber or other pieces of wood-blocks Cardboard boxes of all sizes Small toy cars Cans—all sizes, metal, cardboard, coffee, etc. Plastic bottles, all sizes Spools Film cans Coat hangers	Tooth picks Popsicle sticks Legos Miscellaneous small toys Toy soldiers/dolls Playing cards Rulers Cans Pipe cleaners

Advise students: GRAB ANY RANDOM JUNK YOU FIND—YOU NEVER KNOW WHAT MIGHT BE USEFUL UNTIL YOU ACTUALLY START BUILDING A MACHINE.

Step 2: Establish criteria for quality machines

Criteria (rubric) for evaluating Rube Goldberg Machines
If one were using a point-based rubric, these might be categories for complete score.

Rube Goldberg machines should:

1. Be interesting, creative, and entertaining
2. Accomplish a specific task (pop a balloon, knock over the toy soldier, get the cup in the ball, feed the dog, turn on the computer, make toast . . .)
3. Work without human intervention—once it is begun, no human help can be used to "move it along."
4. Work consistently—no wishful thinking; each time the machine is operated it should work correctly.
5. Be as complex as possible—include as many interactions as possible

Step 3: Machine building and process

Engineer's Problem Solving Cycle

Refer to the diagram for the Engineer's Problem Solving cycle and discuss with the students. The important ideas are that mistakes are not failures, that for each attempt one must carefully observe, think, and make adjustments. Only after many attempts can success be expected. This is true for the greatest inventions ever created.

Have students begin by making drawings of their machine ideas, and considering the tasks that the machine will accomplish, prior to actually building.

Facilitator/teacher coaching guidelines:

1. Don't do their learning for them.
2. What often looks like play is very often very productive work. Remember, Richard Feynman made the key discoveries for his Nobel Prize while doing work that seemed "pointless" to most of his colleagues—when he said the heck with it, and just started playing with things that captured his curiosity, working for fun.
3. Use restraint re. the extent to which you intervene in groups.
4. Remember that the purpose of the workshop is not to create highly finished products, but to afford the kids a powerful learning experience. There is a difference . . .
5. Students must be allowed to struggle and sort out dilemmas on their own.
6. It is "ok" and *expected* for design teams to change their designs as they build, test and observe. That is part of the learning process, to let them discover the impracticality and/or unclear thinking in their designs on their own.
7. Use simple, low stakes questions to facilitate their thinking and productivity such as:
   - What is the task of your machine?
   - What are you considering right now?
   - What is this thing for, what is its function in your machine?
   - Is this design different from your original design?
   - Why are you smashing that can with the blunt end of the scissors?
   - What will water do to your paper funnel?

Step 4: Presenting Machines

Student groups should each present their machines to the class using the oral presentation format provided. This is a wonderful opportunity to explore and reinforce the physics concept of the unit.