**Fantastic Elastic (Grades 2-3)**

Teacher’s Guide

Overview

This unit develops concepts of energy and engineering through design, construction and testing of an elastic powered vehicle, a wind-up. To operate a wind-up, a user stores potential energy in a rubber band, and then releases it, converting the energy to kinetic form, and thereby powering the vehicle. Students begin by looking at the operation of a sample wind-up, and then think about how to make their own. As they create wind-ups, they record issues that arise, learn about troubleshooting, and write their own troubleshooting guides. They make more wind-ups and learn how to experiment with them. Finally they develop and test instruction manuals, and present the results of their work.

Common Core Learning Standards for ELA

Common Core Writing Standards 2-3

**Text Types and purposes**

2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately using linking words to sequence ideas and illustrations to aid comprehension.

3. Write narratives of real experiences using effective technique, descriptive details, and clear event sequences.

**Production and Distribution of writing**

4. Produce writing in which the development and organization are appropriate to task and purpose.

5. With guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising and editing.

**Research to Build and Present Knowledge**

7. Conduct short research projects that build knowledge about a topic.

Common Core Speaking and Listening Standards 2-3

**Comprehension and Collaboration**

1. Engage effectively in a range of collaborative discussions with diverse partners, building on others’ ideas and expressing their own clearly.

**Presentation of Knowledge and Ideas**

4. Recount an experience with appropriate facts and relevant, descriptive details, speaking clearly at an understandable pace.

Common Core Language Standards 2-3

**Vocabulary acquisition and use**

4. Determine or clarify the meaning of unknown and multiple-meaning words and phrases, choosing flexibly from a range of strategies.

6. Acquire and use accurately general academic and domain-specific words and phrases.

Common Core Learning Standards for Mathematics

Standards for Mathematical Practice

**MP1. Make sense of problems and persevere in solving them:** Understand the meaning of a problem and look for entry points to its solution. Analyze givens, constraints, relationships and goals. Make conjectures about the form and meaning of the solution and plan a solution pathway.

**MP3. Construct viable arguments and critique the reasoning of others:** Understand and use stated assumptions, definitions, and previously established results in constructing arguments. Reason inductively about data, making plausible arguments that take into account the context from which the data arose.

**MP4. Model with mathematics:** Identify important quantities in a practical situation, and map and analyze their relationships mathematically. Interpret mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose.

**MP 6. Attend to precision:** Communicate precisely to others, using clear definitions of concepts and symbols and carefully formulated explanations.

**MP 7.** **Look for and make use of structure**: Look closely to discern a pattern or structure.

Standards for Mathematical Content (Grades 2 & 3)

**2. MD & 3.MD Measurement and Data**2.MD1-4: Measure and estimate lengths in standard units  
2.MD 9 & 10; 3MD3 & 4: Represent and interpret data

**2.G & 3.G Geometry**2.G1; 3G1: Reason with shapes and their attributes

Next Generation Science Standards/ Frameworks for K-12 Science Education

Dimension 1: Scientific and Engineering Practices:

1. **Asking questions and defining problems:** Students should be able to ask questions of each other about the phenomena they observe and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution.
2. **Developing and using models:** Students should be asked to use diagrams, maps and other abstract models to as tools that enable them to elaborate on their own ideas, develop explanations and present them to others.
3. **Planning and carrying out investigations:** In the elementary years, students’ experiences should be structured to help them learn to define the features to be investigated, such as patterns that suggest causal relationships.
4. **Analyzing and interpreting data:** At the elementary level, students need support to recognize the need to record observations – whether in drawings, words or numbers – and to share them with others.

**6. Constructing explanations and designing solutions:** The process of developing a design is iterative and systematic, as is the process of developing an explanation in science. Elements that are distinctive in engineering include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing or testing models or prototypes, selecting among alternative design features, and refining design ideas based on the performance of a prototype.

**7. Engaging in argument from evidence:** In engineering, reasoning and argument are essential to finding the best possible solution to a problem. At an early design stage, competing ideas must be compared (and possibly combined), and the choices are made through argumentation about the merits of the various ideas pertinent to the design goals.

**8. Obtaining, evaluating and communicating information:** In engineering, students need opportunities to communicate ideas using appropriate combinations of sketches, models and language. They should also create drawings to test concepts and communicate detailed plans; explain and critique models, and present both planning stages and ultimate solutions.

Dimension 2: Crosscutting concepts:

1. **Patterns:** Noticing patterns is often a first step to organizing and asking scientific questions about why and how the patterns occur. In engineering, it is important to observe and analyze patterns of failure in order to improve a design.
2. **Cause and effect: mechanism and prediction:** Any application of science, or any engineered solution to a problem, is dependent on understanding the cause-and-effect relationships between events. The process of design is a good place to start, because students must understand the underlying causal relationships in order to devise and explain a design to achieve a specified objective.
3. **Systems and system models:** A system is an organized group of related objects or components that form a whole. Models can be valuable in predicting a system’s behaviors or in diagnosing its problems and failures. Students express their thinking with drawings or diagrams and with written or oral descriptions. They should describe objects in terms of their parts and the role those parts play in the functioning of the object.
4. **Energy and matter: flows, cycles and conservation:** Laws of conservation of matter and energy provide limits on what can occur in a system, whether human-built or natural. The ability to examine, characterize and model the transfers and cycles of matter and energy is a tool that students can use across virtually all areas of science and engineering.

**6. Structure and function:** The functioning of systems depends on the shapes and relationships of certain key parts, as well as on the properties of the materials. Exploration of the relationship between structure and function can begin in the early grades through investigations of accessible systems in the natural and human-built world.

**7. Stability and change:** Much of science and mathematics has to do with understanding how change occurs in nature and in social and technological systems, and much of engineering has to do with creating and controlling change.

Dimension 3: Disciplinary Core Ideas – Physical Science:

**Core Idea PS2: Motion and Stability: Forces and Interactions**Interactions between any two objects can cause changes in one or both of them. An understanding of the forces between objects is important for describing how their motions change, as well as for predicting stability or instability in systems.

**Core Idea PS3: Energy**Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Energy manifests itself in multiple phenomena, such as motion, light, sound, electrical and magnetic fields and heat energy.

Dimension 3: Disciplinary Core Ideas – Engineering, Technology and Applications of Science

**Core Idea ETS1: Engineering Design**Identification of a problem and the specification of clear design goals, contending with constraints, using models to better understand the features of a design problem, compare designs, test them and compare their strengths and weaknesses. Selection of a design often requires making trade-offs among competing criteria.

Curriculum Map

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Summary** | **Approx. time (min.)** | **Vocabulary** | **Assessment Methods** |
| 1 | **What is a Wind-up?** | Students observe a wind-up, identify its materials, draw it and begin to make their own wind-ups. | 100 | wind-up, energy, stored energy | Observation, discussion, written work |
| 2 | **Make a Wind-up** | Recording the issues that arise as students attempt to make wind-ups | 50 | potential energy, elastic energy, kinetic energy | Observation, discussion, written work |
| 3 | **Troubleshooting  Wind-ups** | Developing methods for addressing the issues in wind-up operation | 50 | cause, fix, troubleshooting, friction | Observation, discussion, |
| 4 | **Observing Differences and Making a Standard Wind-up** | Observing and discussing different ways to make wind-ups, and differences in their performance, agree on a common way to make a wind-up and make a standard wind-up based on this method | 100 | variable, design variable, performance variable, experiment, standard design, fair test | Observation, discussion, written work |
| 5 | **Exploring How a Wind-up Works  & Writing a Troubleshooting Guide** | Comparing wind-up drawings, discussing energy concepts and writing troubleshooting guides | 100 | opaque, transparent, transformation of energy, input, output | Observation, discussion, written work |
| 6 | **Plan an experiment on effect of wheel size** | Planning an experiment that will explore the effect of wheel size on the operation of a wind-up | 50 | experiment, compare, opinion, evidence, distance, measure, data, data table, diameter | Observation, discussion, |
| 7 | **Conduct an experiment on the effects of wheel size** | Carrying out the experiment on the effect of wheel size by measuring the distances traveled by wind-ups with different wheel sizes | 50 | pattern, cause, effect, fair experiment, generalize | Observation, discussion, written work |
| 8 | **Experiment with Number of Turns** | Planning and conducting an experiment to determine how the number of turns affects the distance traveled by a wind-up | 100 | variation, average | Observation, discussion, written work |
| 9 | **Redesigning and Customizing Wind-ups** | Redesigning wind-ups for esthetic appeal | 50 | mechanism, customize, spin, roll, animate, vertical , horizontal, esthetic, art | Observation, discussion, written work |
| 10 | **Make a Wind-up for the Show** | Continuing to design and make a fancy wind-up for the auto show | 50 |  | Observation, written work |
| 11 | **Illustrated instruction manuals** | Writing illustrated instruction manuals showing how to make wind-ups | 100 | Instruction manual | Written work |
| 12 | **The Wind-up Show** | Presenting wind-ups to an audience, explaining how they were made and how they work | 100 |  | Presentation |

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| --- | --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Standards alignment** | | | | |
| **CCLS -- ELA** | **CCLS -- Math** | **NGSS – Scientific & Engineering Practices** | **NGSS – Crosscutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 1 | **What is a Wind-up?** | **Writing**: Text types and purposes; Production and distribution of writing **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  8. Obtaining and evaluating information | 1. Patterns 6. Structure and function | ETS1: Engineering Design |
| 2 | **Make a Wind-up** | **Writing**: Text types and purposes  **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems   6. Designing Solutions 8. Obtaining and evaluating information | 1. Patterns 4. Energy and matter 6. Structure and function | PS3: Energy ETS1: Engineering Design |
| 3 | **Trouble-shooting  Wind-ups** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  3. Planning and carrying out investigations  4. Analyzing and interpreting data  7. Engaging in argument from evidence  8. Obtaining and evaluating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function | PS2: Motion and stability: forces and interactions ETS1: Engineering Design |
| 4 | **Observing Differences and Making a Standard Wind-up** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use | MP2: Reason abstractly  MP6: Attend to precision  MP7: Look for and make use of structure  2.G1 & 3G1Reason with shapes & their attributes | 1. Asking questions and defining problems  8. Obtaining and evaluating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function 7. Stability and change | PS2: Motion and stability: forces and interactions |

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| --- | --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Standards alignment** | | | | |
| **CCLS -- ELA** | **CCLS -- Math** | **NGSS – Scientific & Engineering Practices** | **NGSS – Crosscutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 5 | **Exploring How a Wind-up Works  & Writing a Troubleshooting Guide** | **Writing**: Text types and purposes; Production and distribution of writing; Presentation of Knowledge and Ideas **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  4. Analyzing and interpreting data  7. Engaging in argument from evidence  8. Obtaining, evaluating and communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction  4. Energy and matter  6. Structure and function | PS3: Energy  ETS1: Engineering Design |
| 6 | **Plan an experiment on effect of wheel size** | **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  3. Planning and carrying out investigations | 1. Patterns 6. Structure and function | . |
| 7 | **Conduct an experiment on the effects of wheel size** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use | MP2: Reason abstractly  MP6: Attend to precision  MP7: Look for and make use of structure   2.MD 1-4 Measure and estimate lengths 2. MD 9&10; 3.MD 3&4 Represent and interpret data | 3. Planning and carrying out investigations  4. Analyzing and interpreting data  7. Engaging in argument from evidence  8. Obtaining, evaluating and communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function 7. Stability and change | PS2: Motion and stability: forces and interactions |
| 8 | **Experiment on effect of number of turns** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use | MP2: Reason abstractly  MP6: Attend to precision  MP7: Look for and make use of structure  2. MD 9&10; 3.MD 3&4 Represent and interpret data | 1. Asking questions and defining problems 3. Planning and carrying out investigations  4. Analyzing and interpreting data  7. Engaging in argument from evidence 8. Obtaining, evaluating and communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function 7. Stability and change | PS3: Energy |

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| --- | --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Standards alignment** | | | | |
| **CCLS -- ELA** | **CCLS -- Math** | **NGSS – Scientific & Engineering Practices** | **NGSS – Crosscutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 9 | **Redesigning and Customizing Wind-ups** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  6. Designing Solutions | 1. Patterns 6. Structure and function | ETS1: Engineering Design |
| 10 | **Make a Wind-up for the Show** |  |  | 1. Asking questions and defining problems  6. Designing Solutions | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function 7. Stability and change | PS2: Motion and stability: forces and interactions  PS3: Energy  ETS1: Engineering Design |
| 11 | **Illustrated instruction manuals** | **Writing**: Text types and purposes; Production and distribution of writing; Research to build and present knowledge **Language**: Vocabulary acquisition and use |  | 1. Asking questions and defining problems  6. Designing Solutions  8. Obtaining, evaluating and communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function | ETS1: Engineering Design |
| 12 | **The Wind-up Show** | **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and use |  | 8. Obtaining, evaluating and communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction 6. Structure and function | ETS1: Engineering Design |

Teaching Strategies

**Learning:** People learn by doing, and then reflecting on what they have done. In engineering, the goal is to design and create something new, and new designs rarely work well the first time. The effort to troubleshoot and fix something that doesn’t work provides rich motivation for learning. This curriculum unit provides numerous opportunities for students to explore for themselves, make things based on what they have learned, and reflect on their work in both oral and written form. Just as there is no one way to design something new, there is no one way to teach this unit. Be creative and flexible, and your students will be too!

**Vocabulary:** Words are not very meaningful unless they are connected with concepts. For this reason, we do not believe in presenting vocabulary words at the beginning of a lesson. Provide students with experiences that allow them to develop the concepts for themselves, and encourage them to use *their own words* to describe these concepts. *Then* provide the words that professional scientists and engineers use to describe these same concepts. These are the words provided in the Vocabulary column of the curriculum maps and the Word Bank section of each lesson. The Glossary at the end of this unit provides a working definition for each word.

**Writing and Drawing:**

Writing and drawing are essential parts of engineering design. The person who created something new is the only person who can describe what they did, and is may be strongly motivated to convey these original ideas to others. This curriculum unit provides numerous opportunities for students to make sense of what they have done through text and graphics. They are encouraged to describe what they plan to make, the issues that prevented it from working, how someone else could make it, how it works and what was learned from it.

As much as possible, students need to express themselves in their own words (see Vocabulary, above), with no more prompts than necessary to get them started. The boxes labeled Science Notebook and the worksheets in the lessons provide starting points. These can be used in any combination, and students should also have opportunities to do more open-ended writing, for example to reflect on how they feel about their work.

Science Notebook entries are boxed.

* Writing prompts have lightning bullets.

Writing in notebooks and worksheets is primarily for the students themselves – to help them consolidate and remember what they have learned and communicate it to others – but it also serves as an assessment tool. It should not be marked closely for grammar and spelling. However, it is appropriate to ask students to read what they have written to the class, and to challenge them to clarify ideas that are unclear or incomplete. Much of the description will require drawings or diagrams as well as text, and it is important to help students learn to coordinate these two modes of communication.

**Discussion**:

Speaking and listening are essential forms of literacy and are central to learning science and engineering. The purpose of a discussion, like that of writing and drawing, is to create meaning. A discussion is not a question-and-answer session led by the teacher, nor a sharing session in which students simply report on what they did. Making meaning requires that students listen and respond to one another’s ideas. In a discussion of engineering design, students may want to bring up issues that they have encountered. Other students may respond by identifying similar issues, and/or by suggesting solutions that they have come up with. As the teacher, your role is to facilitate this give-and-take, by posing questions for discussion and then maintaining focus within the group. Sample focusing questions are identified like this within each lesson:

* *Lightning bullets and italics indicate prompts for discussion*

**Reference:** Worth, K., Winokur, J. Crissman, S., Heller-Winokur, M. (2009) The Essentials of Science and Literacy: A Guide for Teachers. Portsmouth, NH: Heinemann.

Structure of the Lesson Plans

The following categories appear in each lesson (\*), or most lessons (\*\*):

**\*Essential Question**

**\*Task**

**\*Standards**

**\*Outcomes**

**\*Assessment**

**\*\*Advance Preparation**

**\*Materials**

**\*Procedure**

**\*\*Word bank**

**\*\*Worksheets**

Overview of Basic concepts

Like almost any vehicles, the operation of wind-ups provides rich examples of how **energy can be stored and converted** from one form to another. The energy transformations in a wind-up are summarized in Table 1. As energy changes from one form to another it is never created nor destroyed. This last principle is called the **Law of Conservation of Energy**.

Let’s begin with the energy we put into wind-ups. We wind the stick of the wind-up with our hands. Our hands and arms are moving. The energy of anything in motion is called **kinetic** or **mechanical energy**. Where do we get that energy from? Working backwards, all of the energy we have comes from food and beverages, which store **chemical energy** in a form that our bodies can make use of. Energy that is stored is available for use later, but not now. Another word for stored energy is **potential energy**. The energy stored in food or beverages originates from plants, even if we eat meat, whose energy came originally from the plants eaten by an animal. The chemical energy that is stored in plants is the result of **photosynthesis**, which converts **solar (or light) energy** from the sun into chemical energy. Ultimately, we are all solar-powered!

Next, let’s look forward in the process. What happens as we exert energy into winding the stick? As the rubber band stretches, it converts this energy into a form called **elastic energy**, which is the energy of something that is twisted, stretched or squashed, but “wants” to come back to its original shape. Elastic energy is a form of **potential energy**, because it is being saved up for later. Energy is stored in the rubber band or balloon until the wind-up is released. At that point, the stored energy is converted into the energy of motion, which we have already identified as **kinetic** or **mechanical energy**.

Eventually, the wind-up will stop rolling. What happens to its energy? When the wind-up stops, it has no kinetic energy any more, which seems to suggest that its energy was lost – but the Law of Conservation of Energy says that can’t happen. What actually happens is very subtle. The energy of the wind-up is not destroyed, but it is changed from kinetic energy to a form that cannot be used. What slows the wind-up is **friction**, the enemy of all moving things. Table 1, below, summarizes the energy relationships involved in the wind-up operation.

Table 1: Energy relationships involved in wind-up operation

|  |  |  |
| --- | --- | --- |
| **Action** | **Energy transformation** | **Outcome** |
| Sun shines on plants. | Light energy from the sun is converted to chemical energy via photosynthesis. | Plants store chemical energy. |
| People eat food. | Stored chemical energy is added to our bodies. | People store chemical energy. |
| Food is metabolized. | Chemical energy becomes available to muscles, which convert it to kinetic energy. | People can move their body parts. |
| A person turns the stick of a wind-up | Kinetic energy gets converted into elastic energy in the rubber band. | The rubber band stores potential energy, for later use. |
| The person releases the wind-up. | The elastic energy of the rubber band gets converted into kinetic energy of the wind-up. | The wind-up travels across the floor. |
| The wind-up slows down. | The kinetic energy is gradually transformed into heat energy, due to friction between the wind-up and the floor and air. | The wind-up eventually stops. The floor, wind-up and surrounding air all heat up very slightly. |

Teacher Notes on the Lessons

Lesson 1: What is a Wind-up?

There are three basic types of motion you can get from a wind-up:

1. A wind-up that goes along a straight line;
2. A wind-up that goes in a circle;
3. A wind-up that either spins in place, or seems to twist and turn at random.

We suggest you begin by making either type a) or b) or both. In case you would like to make all three, we have provided directions for making each of the three types.

a) Making a wind-up that goes straight

Figure 1 shows the materials you will need.

Figure 1: Materials for making a basic wind-up

Before assembling the wind-up, you will need to make a small hole near the center of each lid, and another hole in the bottom of the cup. The holes should be big enough that you can get the rubber band through, but not so big that the paper clip or bead will fall through.

To assemble the wind-up, the rubber band will need to go through the two lids, cup, and bead. It will be held in place by going around the stick and paper clip. First place the parts in the order shown in Figure 2 below.

To assemble the wind-up, pull the rubber band through the hole in the lid on the left, and capture it with the paper clip. Then pull it in the other direction through the cup, the lid on the right, and the bead. If it’s hard to get the rubber band through the holes, there are suggestions in the Teacher Notes for Lesson 2.

After getting the rubber band through the bead, capture the open end of the rubber band by wrapping it around the stick. Adjust the stick so only one end of it is extending past the edge of the lid. F shows the assembled wind-up.



Figure 2: Parts for making a wind-up, laid out in order



Figure 3: Finished product

b) Making a Wind-up that goes in Circles

The only difference between this wind-up and the one that goes straight is the size of one of the wheels. To go in circles, one wheel needs to be smaller than the other. Make a wind-up using a lid at the big end of the cup, but no lid at the small end. Use the small end of the cup to hold the paper clip. The diagram below shows the difference between the two. On the left, the lid you do not want is shaded; on the right is the wind-up that goes in circles, because it has only one lid.



Figure 4: A wind-up that goes in circles

c) Making a Wind-up that Spins in Place or Moves Randomly

To make a wind-up that acts unpredictably, you need two small wheels. To understand why, consult the Teacher Notes for Lesson 5.

Use the small lids, about 2 ¾” diam., instead of the larger ones. You can’t use the cup to separate them, because the big end of the cup is too large to hold the small lid. Instead, you can either:

1. Use a small wooden or plastic spool, if one is available, or
2. Make a separator by creating a triangular tube out of cardstock, as shown in Figure 5.



Figure 5: How to make a separator from a piece of cardstock

Now use the same materials as before except:

* Use the triangular tube instead of the cup,
* Use two small lids instead of two large ones, and
* Use the shortest stick available, such as a 6 ″ wooden skewer.

Use these parts to make a wind-up, the same way as before. The Figures 6 and 7 below show how it looks before and after assembly.



Figure 6: Parts shown in order of assembly for making small wind-up



Figure 7: Small wind-up, after assembly

Lesson 2: Make a Wind-up

How energy is transformed in a wind-up

The wind-up has an input and an output. The input is the turning of the stick while holding the cup firmly. The output is the movement of the wind-up. Between the input and output the following things happen:

1. Kinetic energy is used to turn the stick of the wind-up. This energy goes into:

* twisting the rubber band and in doing so stretch the rubber band.
* overcoming friction between the parts that move relative to each other as the stick is turned.

1. The energy used to twist and stretch the rubber band is converted to elastic energy, which is a form of potential energy stored in the rubber band.
2. When the windup is placed on the floor and the stick is then released, the only way for the rubber band to unwind will be for the cup to begin turning, because the floor will keep the stick from turning. The turning of the cup will cause the wind-up to travel across the floor. The body of the wind-up will rotate, turning the potential energy stored in the rubber band back into the kinetic energy of motion of the wind-up.



Figure 1: Wind-up placed vertically on a table or other surface, ready to spin

1. When the wind-up is placed on a surface with the stick on top, as shown in Figure 1, it will be easier for the stick to spin than for the body to spin, so the potential energy stored in the rubber band will be converted into kinetic energy mostly of the stick. As the stick spins, it will usually cause the body of the wind-up to vibrate or even dance.

Lesson 3: Troubleshooting Wind-ups

Getting the wind-up to stay together

The initial problem in making a wind-up is to adjust the length of the rubber band and the cup or tube, so that when it is not stretched, the rubber band is only slightly shorter than the tube. If the rubber band is too long compared with the distance between the ends, the construction will not stay together. To address this issue:

* Use a shorter rubber band;
* Double the rubber band or wrap it around the stick a few times to make it shorter; or
* Keep ends farther apart by using a longer cup or tube.

Another reason the wind-up might not stay together is that the rubber band could slip through the hole in the wheel that was holding the paper clip. If the hole is too big, use a larger paper clip, or a cup or lid with a smaller hole.

Getting the rubber band through the holes

In making a wind-up, the rubber band has to be threaded through several holes: a hole through each wheel (which may be a lid or the bottom of the cup) and a hole in the bead. The holes in the wheels are not usually hard to get through, but they shouldn’t be too big that the bead or paper clip could fall through (see previous paragraph). The biggest problem is usually getting the rubber band through the bead. Here are some solutions:

* Make a hook from a small paper clip, and use the hook to pull the rubber band through;
* Wrap a short length of stiff fishing line or thin wire around the rubber band, and use the line or wire to pull the rubber band through; or
* Use a stiff wire or barbecue skewer to push the rubber band through.

Getting the wind-up to move

For a wind-up to go, the rubber band has to be able to turn the wheels. This happens when the rubber band unwinds. In order to unwind, one end of the rubber band has to be fixed so the other end can rotate. In the sample wind-ups, the stick is prevented from turning by dragging on the floor. This provides a base for the rubber band to unwind against. The other end of the rubber band should be attached to one of the wheels (lids). This is the job of the paper clip in the sample wind-ups. A good way to troubleshoot a wind-up that won’t go is to hold it off the floor or table, and see what happens after you wind up the stick. Three possibilities are:

1. The stick turns,
2. The stick and paper clip both rotate, or
3. Nothing turns.

Let’s look at each of these cases separately.

1. The stick turns, but not the paper clip: If the stick turns when the wind-up is off the ground, but won’t make the wind-up go when it is on the floor, it might just need to be wound up some more! Another possibility is that the stick is probably too short. Use a longer stick, or adjust it so it extends past the edge of the lid on one side.
2. The paper clip and stick both turn: The problem here is that the paper clip isn’t transmitting the motion to the lid. Use some tape to make sure the paper clip and the lid turn together.
3. Nothing turns: This is the hardest one to solve, because there are several possible causes:
4. The most obvious problem is that the stick just hasn’t been wound up enough. The first thing to try is to wind it up some more, but not so much that the rubber band breaks!
5. Next, check whether the stick is rubbing against the lid. If so, the **friction** between the two is probably what’s preventing the stick from turning. Add a bead, a larger bead or a second bead to separate the stick from the lid.
6. Finally, see if the rubber band is too short, and therefore too tight. If it is, this will also add to the friction. Test it by pulling the lid gently away from the cup or tube. If it is hard to do, the rubber band is probably too tight. The solution is to use a longer rubber band, to chain two rubber bands together, or to use a shorter cup or tube. When the rubber band is untwisted, it should be only slightly shorter than the tube or lid.

Table 1 below shows a sample troubleshooting chart, which summarizes much of the information above.

Table 1: Troubleshooting chart

|  |  |
| --- | --- |
| Issue: Wind-up doesn’t go |  |
| Cause | Fixes |
| Stick rubs on lid | Put a spacer between the stick and the lid, such as a bead or button or piece of wax, to hold the stick away from the lid |
| Rubber band holds everything too tightly together | Use a longer rubber band.  Use a rubber band that is not so thick and strong |
| Not wound up enough | Wind it up more and see if that works |

The role of friction in the wind-up

Friction is the enemy of moving parts. It prevents one from moving independently of the other. Sometimes friction is necessary for a wind-up to work, and sometimes it prevents the wind-up from working. Table 2 provides examples of both kinds of situation.

Table 2: Friction: Friend or Foe?

|  |  |  |  |
| --- | --- | --- | --- |
| **Surfaces in contact** | **Possible Problem** | **Amount of friction** | **Solution** |
| Stick and wheel | Stick rubs against wheel, preventing wheel from turning freely | Too much | Put a bead between the stick and the wheel to reduce friction |
| Stick, bead and wheel | Stick, bead and wheel are pulled together so tightly by the rubber band that they can’t run easily. | Too much | Use a longer, or weaker, rubber band to reduce the force holding parts together and thus reduce friction |
| Paper clip and wheel | Paper clip turns, but doesn’t make wheel turn | Not enough | Use tape or tighter rubber band to increase friction |
| Wheel and floor | Wheel slips on floor; wind-up won’t move forward | Not enough | Add a tire around the wheel to increase friction, or use a larger wheel |
| Wind-up, floor and air | Wind-up eventually slows down and stops | Unavoid-able | No solution – this is happens to every moving thing unless additional energy is supplied to make up for friction |

NOTES

* The bead is used to reduce friction: In the Troubleshooting section of Lesson 2, we explained that the bead is needed between the stick and the wheel to reduce the friction between them. If there stick is too tight against the wheel, there will be too much friction and the stick and wheel will not be able to move independently.
* A longer or weaker rubber band reduces friction: In the Troubleshooting section of Lesson 2, we explained that the friction between the stick, bead and lid can be reduced by reducing the force from the rubber band that holds them together. This can be done by using a longer rubber band or a thinner one.
* The paper clip and lid require friction to keep them together. They need to move as one, or the turning paper clip won’t make the car go.
* Some friction is needed between the wheel and the floor. If the wheels are small, they will slip on the floor, and the wind-up will spin in place rather than travel forward. See Lesson 6. Like a car wheel, something rough is needed to make the wheel “grab the road.” A car uses a rubber tire to increase the friction between the wheel and the road. Of course, too much friction will not work, which is why wheels should not be square.
* Friction stops the wind-up from going on forever. As the wind-up is rolling, there is some friction between the wheels and the floor, between the whole wind-up and the surrounding air, and also between the stick and the bead. All of this rubbing causes everything to heat up ever so slightly – probably much less than you can notice – but accounting for all the energy the was previously kinetic. Energy “lost to friction” is not actually being destroyed – it is being converted from mechanical energy to heat energy, which is “lost” only in the sense that it can no longer be used.

Lesson 4: Observing Differences and Making a Standard Wind-up

For students who are reluctant to make drawings, provide individual or group instruction in basic drawing skills. Begin by showing them a lid, and asking what shape they see. Then ask them to draw a circle. Continue in a similar way with each of the other wind-up parts. Figure 1 below shows how each part – except the paper clip – can be represented by a very simple shape or line drawing:



Figure 1: Wind-up materials

In Figure 1, all of the parts are seen head-on, which is not how they would all look when assembled into a wind-up. Ask students to draw a lid as it is seen from the side. It no longer looks like a circle! The next step is to show the parts from the view you would see when looking at an assembled wind-up, as in Figure 2:



Figure 2: Wind-up materials from a side view

Figure 2 shows the parts from a wind-up, all in the same view, but not in the order you would need to assemble a wind-up. The next steps are to show them in order, just before and after assembly. These are shown in Figures 2 & 3 on p. 12, using the same parts as in Figures 1 & 2 on this page.

Lesson 5: Exploring How a Wind-up Works & Writing a Troubleshooting Guide

How a wind-up works

1. **Twisting the rubber band**: When you turn the stick, you are twisting the rubber band. It “wants” to unwind, but you are preventing it from doing so by holding the stick with one hand and the body of the wind-up with the other.
2. **What is actually turning**: By looking closely at a wind-up as it is operating, students should notice that:

* The stick does not turn. The floor or table top should prevent the stick from turning.
* The bead may or may not turn. Its job is to allow the wheel to turn while the stick stays against the floor.
* The rubber band unwinds.
* The paper clip and both wheels turn.

1. **Untwisting the rubber band:**  The rubber band can’t unwind unless it is allowed to rotate freely at one or both ends. Here is a scenario in which the rubber band can’t unwind at all. It also describes the outcome of the first experiment in Step 5 of Procedure.

Experiment a) Two sticks: If the paper clip is replaced by a stick, there will be a stick at either end of the rubber band. Both sticks are resting on the floor, so neither will be able to turn. In this case, the rubber band will be held at both ends, and will not be able to unwind at all. In order for the rubber band to unwind, at least one end must be able to rotate.

1. **Turning the wheel**: Let’s suppose the stick touches the floor, so it holds the rubber band at one end. What should happen at the other end? For a wind-up to move, the other end of the rubber band has to make the wheel turn at the other end. Here are two scenarios in which this won’t happen. They correspond to Experiments b) and c) in Step 5 of Procedure:

Experiment b) One short stick: If the stick is too short, it may not rest on the ground; in that case, both ends of the rubber band will be free to turn. The short stick will be easier to turn than the wheel, so the stick will spin freely, but the wheel won’t turn and the wind-up won’t go.

Experiment c) Paper clip spins: In this case, there is a stick on one end, which gives the rubber band a base to turn against, but on the other end, only the paper clip will spin, because it is not attached to the wheel. As a result, there is nothing to make the wheel turn, and so the wind-up will not go. Sometimes there is enough friction between the paper clip and the wheel to hold them together. If not, a little tape will do the job.

The outcomes of all three experiments are that:

a) **There can only be a stick on one side**.

b) **The stick has to be long enough to touch the floor or table**.

c) **The paper clip has to be tight enough against the wheel that it carries the wheel with it when it turns.** Sometimes there is enough friction between the paper clip and the wheel to hold them together. If not, a little tape will do the job.

1. **Making the wind-up go**: Here is the sequence of events in a wind-up that works well:

a) As the rubber band unwinds, one side is held in place by the stick, which is resting against the ground.

b) The other end of the rubber end turns the paper clip as it unwinds.

c) Because the paper clip is tight against a wheel, the paper clip makes the wheel turn too.

d) The wheel that turns is attached to the cup and the other wheel by the rubber band, so these rotate too.

e) The rotating cup and two wheels drag the bead and the stick along with them.

Lesson 6: Plan an Experiment on the Effects of Wheel Size

Effects of wheel size

Two major effects of wheel size are on the distance a wind-up will travel and the speed with which it will go. All other things being equal (see Controlling variables, below), a wind-up with larger wheels will travel farther, but more slowly than a wind-up with smaller wheels.

Why do larger wheels make a wind-up go farther?

A larger wheel has a larger circumference – the distance you measure if you put a tape measure all the way around the wheel once. Every time the wheel makes one full rotation, it travels the distance of its own circumference. Every unwinding of the rubber band, corresponding to a turn of the stick, should make the wheel go through one full rotation, making it travel its own circumference. Since a bigger wheel has a bigger circumference, it will travel farther.

Why do larger wheels make a wind-up go more slowly?

The energy that powers a wind-up is stored in the rubber band when the stick is wound up. Each turn of the stick delivers roughly the same amount of energy into the rubber band, regardless of how big the wheels are. This energy is released when the wind-up is let go. If the wheels are large, the same amount of energy has to be distributed over a larger circumference, and therefore a larger distance, so there is less of it to go around each time the wind-up moves a little. Therefore, the larger the wheel size, the more slowly a wind-up will usually go.

How can the data be collected and analyzed, to show the effect of wheel size?

Two outcome variables that can be measured are speed and distance traveled. Speed requires measurements of both distance and time, while the wind-up is moving. and then the calculation that:

Speed = distance/time

The total distance traveled can be found with a tape measure, or by counting floor tiles, after the wind-up stops. Of course, the starting point has to be known, or there will be no reference to measure from. It does not require any measurements of time, nor any measurements to be made while the wind-up is moving. For these reasons, distance traveled is much easier to measure and record than speed.

Collecting and recording data

A simple way to collect data would be to measure the distance traveled by wind-ups with both small and large wheels. This data should be recorded separately, so that it is clear how far each type of wind-up went. For example, you can set up a chart with two columns:

|  |  |
| --- | --- |
| Small wheels | Large wheels |
|  |  |

Distances measured for each wheel type could then be entered in the second row, using the two columns to keep the data separate.

What variables should be controlled in order to have a fair test of the effect of wheel size?

In an experiment, there should be only one independent variable. If more than one variable is changed, it will not be possible to know which of them caused any effect that is observed. The experiment in this lesson is designed to explore the effect of wheel size on the distance traveled by a wind-up. Besides wheel size, there are some other variables that could affect the distance traveled. These include number of turns, cup length, type of rubber band and presence or absence of a bead. All of these variables should be kept the same for both types of wind-up – the only design variable that should change is wheel size. Otherwise it will not be possible to distinguish wheel size from the other factors that could affect the distance traveled.

Lesson 8: Experimenting with the Number of Turns

Errors in conducting the experiment. Based on your own experiments, and observations of the students, make a judgment about how much variation in the data is reasonable. During the trials and the full experiments, look for groups or students whose data differs considerably from other data based on the same wheel size and number of turns. Look for issues in the way the experiment was done, for example:

* *Show me how you counted the turns of the stick.*
* *How did you measure the distance the wind-up went?*
* *Where did you start measuring?*
* *Wind the wind-up again and show me how you did the experiment.*

Natural variations in the data. Some level of variation is completely predictable. Wind-ups will wind-ups that go somewhat different distances, even though the wind-ups appear to be made the same way, and wound up with the same number of turns. This variability reflects the fact that there are differences among the wind-ups that we can’t easily see. Some example of such differences are:

* *One rubber band may have already had ten twists before the group began counting the number of twists given to it.*
* *One rubber band may have been wound up and released many times, in the process creating fatigue in the rubber band so it is not as resilient.*
* *One rubber band may be pinched as it passes through the wheel, making it so it does not wind or unwind freely.*
* *The bead separating the stick from the wheel may be smoother and have less friction in one wind-up than in another.*

In the discussion, help children to raise possible differences between the apparently similar wind-ups.

Conclusions from the data. Help students make comparisons between the four quadrants of the class data table. The purpose of these comparisons is to lead to two generalizations:

*1. When the stick is turned more times, the wind-up will go farther.*

This generalization is the result of comparing the left and right columns of the data table. For the rubber band to unwind completely, it must turn the wheel of the wind-up one time for each time the rubber band was turned around. So, if you twist the rubber band more times, it has more times to untwist and thus more times to turn the wheel of the wind-up. Another explanation has to do with energy: if you wind it up more, the rubber band will store more energy. When it is released, this energy will go into making the wind-up travel, and if it has more energy to start with, it will travel farther.

*2. For the same number of turns, a wind-up with larger wheels goes farther than a wind-up with smaller wheels.*

This generalization is the result of comparing data between the top and bottom rows of the data table. The reason for this conclusion is provided in the Teacher Notes for Lesson 6.

Lesson 10: Make a Wind-up for the Show

Assessment: How does a wind-up work?

*1. How does energy get into the wind-up?* Students should recognize that they put energy into the wind-up by turning the stick. The energy they use is kinetic energy, because the hand is moving when it winds the stick. Students may also recognize that the energy they expend comes from the food they have eaten, which in turn, received its energy from the sun. See Table 1, Overview of Basic Concepts on p. 10 for more details.

*2.* *How is the energy stored in a wind-up?* The energy in a wind-up is stored by twisting the rubber band. This form of energy is called elastic or potential energy. It’s elastic because a rubber band can store energy by twisting or stretching, and then release it by going through the reverse process: untwisting or compressing. Potential energy is stored whenever an object or system is not yet completely stable. For example, a rubber band that’s stretched or twisted will not be stable until it is released; a weight that’s lifted above a surface won’t be stable until it falls to the surface.

*3. What happens to the energy when you let the wind-up go?* The potential energy stored in the rubber band is released by turning one of the wheels, which in turn drives the wind-up. The details of this process are described in the Teacher Notes for Lesson 5, p. 21.

*4. Where does a wind-up need friction in order to work?* Two answers are: a) there needs to be friction between the paper clip and one wheel; and b) there needs to be friction between the wheel and the surface it is riding on:

a) The paper clip transfers the motion from the unwinding rubber band to one of the wheels. If the paper clip slips against the wheel, the wheel will not turn and the wind-up will not go.

b) The wheel needs some friction with the surface of the table or floor. Otherwise it will slip, and not have enough traction to propel itself forward. This is what happens when a car wheel is slipping against ice or mud. A way to increase this type of friction is to wrap a rubber band around the wheel, forming a tire.

*5. Where can friction prevent a wind-up from working?* For a wind-up to work, the stick has to remain in one position while the wheel it is near can rotate. This means that one part (the wheel) has to be able to move with respect to another (the stick), which requires that there not be too much friction between them. If the stick is rubbing directly against the wheel, there will likely be too much friction to prevent the wheel from turning freely. A solution to this problem is to put a bead or other spacer between the stick and the wheel.

**Materials for Fantastic Elastic**

|  |  |  |  |
| --- | --- | --- | --- |
| **Item** | **Detail** | **Qty** | **Lessons** |
| Barbecue skewers | 6", bag of 100 | 1 | 1-12 |
| Masking tape | 1"x 60 yds. | 6 |
| Rubber bands | #33, 3 ½”x1/8” | ¼ lb |
| Paper clips | #1, smooth, box of 100 | 2 |
| Pony beads | Assorted colors | 200 |
| Plastic lids | Dart 12JL, white vented, about 3 ¾” diam. | 100 |
| Paper hot cups | 8 oz. | 50 |
| Barbecue skewers | 8", bag of 100 | 2 | 2-12 |
| Rubber bands | #30, 2”x 1/8” | ¼ lb |
| #64, 3 ½”x ¼” | ¼ lb |
| #61, 2”x ¼” | ¼ lb |
| #19, 3 ½”x /16” | ¼ lb |
| #14, 2’x 1/16” | ¼ lb |
| Plastic lids | Dart 4 JL, white vented, about 2 ¾” diam. | 60 |
| Paper saucers | 6" Solo HWP6-J8001 | 100 |
| Paper hot cups | 12 oz. | 50 |
| Reclosable storage bag | 2 gallon | 30 |
| Wire stripper |  | 1 |
| Clear plastic cups | Fabri-Kal Greenware, 7oz. | 30 | 5 |
| Google eyes | assorted sizes | 100 | 9-12 |
| Feathers | assorted sizes & colors | 100 |
| Foam stickers | assorted shapes & colors | 100 |
| Pipe cleaner | assorted colors, 12″ long | 60 |
| Cocktail umbrella | assorted colors, 4″ diam. | 30 |
| Pom-poms | assorted sizes and colors | 100 |

Notes about Materials

\* Note on materials: other materials may be substituted for those listed. The important things to consider in making substitutions are:

* Rubber bands: A # 34 (4” x 1/8”) may be used instead of #33. Shorter rubber bands (i.e. two # 30, 2” x 1/8 ”) may be linked together. However all students must have the same rubber bands for Lessons 4 and 6, 7. and 8.
* Plastic lids: Any circle can be used for a wheel as long as it is bigger than the top of the cup. If a plastic lid is used, be sure it is a smooth circle with no tabs.
* Paper cups are used as the body of the wind-up. The rubber band stretches from one end to the other. If a bigger cup is used it may be necessary to use longer rubber bands, or to link two smaller ones

**Lesson 1: What is a Wind-up?**

## **Essential Question**

How can you make a wind-up vehicle?

## **Task**

Create a wind-up using a cup, lid(s), paper clip, bead, stick and rubber band

## Standards:

CCLS – ELA **Writing**: Text types and purposes; Production and distribution of writing   
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 8. Obtaining and evaluating information.  
**Crosscutting Concepts:** 1. Patterns; 6. Structure and function  
**Disciplinary Core Ideas**: ETS1: Engineering Design

## Outcomes

* A wind-up vehicle can be made from simple materials. You have to turn the stick to make it go.
* To make a wind-up, you can use a stick, cup, one or two lids, bead, paper clip, and rubber band.

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Observe and record the operation of a wind-up | No observation | Observation of wind-up, but little or no recording | Describes basic operation of a single wind-up, including the need to wind the stick | Describes operation of more than one type of wind-up |
| B. Identify materials that can be used to make a wind-up | No materials identified | Identifies some materials, but not others | Identifies all the materials needed to make a particular wind-up | Recognizes variations in the possible list of materials |

## Advance Preparation

* Construct at least one sample wind-up. If possible make one that goes straight, another that goes in circles and a third that moves randomly. See Figure 1, below. For instructions, please read pp. 11-15 in Teacher Notes and/or view the videos at <http://www.citytechnology.org/energy-system/1-what-wind>
* Photocopy worksheet, "My Wind-up".
* Prepare materials for making wind-ups. These can either be provided by sorting out a set of materials for each group, and placing them at each work table, or all the materials can be laid out on a supply table for the entire class.

## 

Figure 1: Three types of wind-ups: One that will go straight (left), another that will go in circles (center)  
 and a third that will spin in place or move randomly (right)

## Materials

* At least one sample wind-up. See Advance Preparation, above.
* Materials for making wind-ups: 6" barbecue skewers, 8 oz paper cups, #33 rubber bands (3 ½”x 1/8") 2 3 ¾ ” cup lids, masking tape, paper clips, pony beads.
* Two-gallon plastic bags for storing work-in-progress – one per student

***Procedure***

1. Things that move (Whole class – 10 min.) Lead a discussion about non-living things that are able to move around on their own:

* *What are some things that are not living, but can move around without someone pushing or pulling them?*
* *What makes it possible for them to do this?*

Help students see that things don’t move unless there is something that causes it. One word that describes the cause of motion is **energy**. If something can move around on its own, it must have a source of **stored energy**. Ask:

* *What do different kinds of vehicles uses as sources of stored energy?*

1. Looking at wind-ups and drawing them (Whole class – 10 min.) Show them a sample wind-up and ask them to identify the parts. List the parts as they are named. Ask:

* *I want to draw this wind-up. How shall I begin?*

Start with the cup and ask students what they see from a side view. Draw the trapezoid, then the narrow rectangles, which is what can be seen of the lids (wheels) from the side. Ask students to name each of the other parts, and ask for volunteers to draw them. Then ask:

* *How will I know what each of these pieces is called?*

Elicit the label for each part and write the labels on the drawing as they are given. Then ask:

* *What will I need to do in order for this to go on its own?*

1. Demonstrate the wind-up (Whole class – 10 min.): As the wind-up is moving, ask:

* *What is making this go?*
* *Where is the energy coming from?*
* *How does the energy get there?*

1. Design a wind-up (Individual – 20 min.): Ask students how they would like to make their own wind-ups:

* *What materials could you use, besides the ones we listed on the drawing?*
* *Make a sketch of what you wind-up will look like.*
* *What issues do you think might come up in putting together your wind-up, and getting it to work?*

They should use the worksheet to address these questions.

**Suggested breakpoint between periods**

## Make a wind-up (Small group – 30 min.): Provide time for students to assemble their own wind-ups. They may want to work individually, but consult with other group members when they run into issues. Allow adequate time for clean-up. Inform the students that they will be able to continue working on their wind-ups in the future, so they keep all work-in-progress in a plastic bag, with each person’s name labeled on each bag.

1. Discussion (Whole class – 10 min.): Lead a discussion about students experiences:

* *How far did you get?*
* *What did you learn from it?*
* *What would you like to do next time?*

1. Reflections (Individual – 10 min.)

Science Notebook

* What did you do today?
* How did you feel about this activity?
* What will you do differently next time?

## Word Bank

wind-up, energy, stored energy

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Date: \_\_\_\_\_\_\_\_\_\_\_\_\_

My Wind-up

Materials I will use:

|  |  |
| --- | --- |
| \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

What it will look like (draw a quick sketch)

Issues that might come up: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lesson 2: Make a Wind-up**

## **Essential Question**

How can you get your wind-up vehicle to work?

## **Task**

Complete the wind-up and get it to work.

## Standards:

CCLS – ELA **Writing**: Text types and purposes  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 6. Designing Solutions; 8. Obtaining and evaluating information.  
**Crosscutting Concepts:** 1. Patterns; 4. Energy and matter; 6. Structure and function  
**Disciplinary Core Ideas**: PS3: Energy; ETS1: Engineering Design

## Outcomes

* Design, construction and testing of a working wind-up vehicle
* Identification of issues that could prevent a wind-up from operating

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Create and test a wind-up vehicle | Does not try to make a wind-up | Makes a wind-up, but does not get it to work | Creates a working wind-up | Creates more than one type of wind-up; assists other students with their wind-ups |
| B. Identify issues that can prevent a wind-up from working | No issues identified | Identifies an issue, but does not express it clearly | Identifies an issue and expresses it clearly | Identifies multiple issues, including issues encountered by others |

## Advance Preparation

* Prepare wind-ups that differ in parts and construction: i.e., two paper plates as wheels, one lid for a wheel, two lids as wheels, different sticks, different cups or tubes to separate the wheels. See Teacher Notes for Lesson 1, pp. 11 – 15 and/or videos under Advance Preparation at <http://citytechnology.org/energy-system/2-make-wind>
* Review energy concepts, using Teacher Notes for Lesson 2, p. 16 and/or the video at <http://www.citytechnology.org/node/2681>
* Organize materials, as in Lesson 1, but including new varieties of lids, cups, rubber bands, skewers and paper saucers (see Materials, below);
* Prepare a Chart with the word Issues on top, and lines for listing the issues that come up in making and operating wind-ups.

## Materials

* Partially completed student wind-ups from Lesson 1, plus storage bags
* Materials for making a variety of wind-ups: 6” and 8” barbecue skewers; masking tape; #33, #30, #64 #61 #19 and #14 rubber bands; 8 & 12 oz. paper hot cups; pony beads; paper clips; 3 ¾ & 2 ¾ “ plastic lids; 6” paper saucers; wire stripper (for cutting skewers).

## Procedure

1. Making wind-ups: (Small group – 30 min.) Students continue working on their wind-ups. Students who have already made wind-ups can make new ones of different types. Provide them with samples of wind-ups with large wheels, small wheels, and different sized wheels. As students are working, ask them to keep track of issues that arise. Post the issues on chart paper. As students ask for help with problems, identify these as issues, by adding them to the chart. Some examples of issues that are likely to come up:

* The rubber band won’t go through the holes.
* The wind-up won’t stay together.
* The wind-up does nothing at all.
* The wind-up moves but won’t go in a straight line.
* The wind-up doesn’t go far enough.
* The wind-up goes too slowly.

1. Wind-up issues and energy (Whole class – 20 min.): Discuss the problems, or issues, students have encountered as they tried to make and operate their wind-ups. List these issues on the chart. In order to relate these issues to energy concepts, use these prompts:Introduce the concepts of **potential energy, stored energy, elastic energy, and kinetic energy and energy of motion**, demonstrating them with the wind-up:
   * *What makes a wind-up go?*
   * *Where does it get the energy to go?*
   * *What is the job of the rubber band? How can you tell?*

Explain that the energy that is waiting to make something go is called **potential energy**. The potential energy in the rubber band is in a form called elastic energy, because it takes energy to twist or stretch the rubber band, and you can get this energy back by letting it go.

* + *What would happen if you replaced the rubber band with a piece of string?*
  + *Why do you have to hold onto the stick before you want the wind-up to go?*
  + *What happens to the potential energy in the rubber band after you let the stick go?*

Use the term **kinetic energy** to describe the energy of the wind-up when it is moving.

* + *When does the wind-up have kinetic energy? How can you tell?*

## Word bank

potential energy, elastic energy, kinetic energy

## Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Lesson 2: The Wind-up I Made

Draw the wind-up you made and label the parts:

List the issues that came up with your wind-up:

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lesson 3: Troubleshooting Wind-ups**

## **Essential Question**

How can we fix a wind-up that doesn’t work the way we want?

## **Task**

Identify causes for the issues in wind-up operation, and fix wind-ups by addressing these causes

## Standards:

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 3. Planning and carrying out investigations; 4. Analyzing and interpreting data; 7. Engaging in argument from evidence;   
8. Obtaining and evaluating information.  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function  
**Disciplinary Core Ideas**: PS2: Motion and stability: forces and interactions; ETS1: Engineering Design

## Outcomes

* Identification of causes that could explain a problem in wind-up operation
* Finding ways to fix the problems in wind-up operation, based on what’s causing them

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Identify causes of issues in wind-up operation | No causes identified | Identifies a cause that could not really explain the issue, | Identifies a possible cause for one issue | Identifies multiple possible causes for an issue |
| B. Identify possible ways to fix an issue by addressing its cause | No fixes identified | Identifies a fix that is not related to the cause | Suggests a fix that would address the cause | Suggests a fix and explains how it would address the cause |

## Advance Preparation

* Prepare a blank Troubleshooting chart, like the one in Table 1, below
* Make a chart showing drawings of two wind-ups: one that has no bead and another that has only one lid, as in Figure 1, below.

Table 1: Troubleshooting Chart

|  |  |
| --- | --- |
| Issue: | |
| Causes | Fixes |
|  |  |
|  |  |
|  |  |

## 

Figure 1: A wind-up that has no bead (left); another wind-up that uses only one lid (right)

## Materials

* Partially completed student wind-ups from Lesson 2, plus storage bags
* Issues chart from Lesson 2
* Materials for making a variety of wind-ups, same as for Lesson 2.

## Procedure

## Troubleshooting (Whole class – 20 min.) Ask the class to select one of the items from the Issues chart, such as “Wind-up doesn’t go,” and lead a discussion about how to handle that issue. Point out that it doesn’t make sense to start over, because most of what you made is probably OK. Also, if you start over, you might just run into the same issue again! It makes much more sense to:

* *Find out exactly what is preventing it from working, and*
* *Then solve only that problem.*

In engineering, this way of addressing issues is called **troubleshooting**.

Write down the issue on the top line of the Troubleshooting chart (see Table 1), and ask students what they think is causing the issue. Record their ideas in the “Cause” column. Then ask what they did or could do about that problem, and put the answer under “Fix.” Sometimes it’s easier to go the other way – Figure out the “Fix” first, and then decide what the “Cause” was. If necessary, model this process by filling in sample causes and fixes, as in Table 1 on p. 17, under the Teacher Notes for Lesson 3.

1. Additional issues, causes and fixes (Small groups – 10 min.): Ask students to think about some of the other issues that have come up with their wind-ups, identify the cause of each one and propose a fix..
2. Friction (Whole class – 10 min.): One of the causes that will probably recur is that one thing is “rubbing” or “pressing” against another. Introduce the word **friction** to describe this problem. On the troubleshooting chart, write the word “friction” under the cause, and ask:

* *If friction between \_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_ is the cause, what could be the fix?*

1. Drawing as an aid in troubleshooting: (Whole class – 10 min.) If a wind-up is clearly drawn, students can often predict how it will behave. Present the chart showing the two wind-ups in Figure 1, and ask:”

* *What do you think each of these wind-ups will do?*
* *Tell me how I could use the drawing to show how you would fix this wind-up to make it work the way you want*

## Word bank

cause, fix, troubleshooting, friction

**Lesson 4: Observing Differences and Making a Standard Wind-up**

## **Essential Question**

What are the differences among different kinds of wind-ups?

## **Task**

Identify differences among wind-ups, select a common type, and make wind-ups that all work the same way

## Standards:

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

CCLS – Math   
**Math Practices**: MP2: Reason abstractly; MP6: Attend to precision; MP7: Look for and make use of structure  
**Geometry**: 2.G1 & 3G1: Reason with shapes and their attributes

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 8. Obtaining and evaluating information.  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function; 7. Stability and change  
**Disciplinary Core Ideas**: PS2: Motion and stability: forces and interactions

## Outcomes

* Identification of differences among wind-ups, including both differences in how they are built and differences in how they perform
* Recognizing cause-and-effect relationships between design variables and performance variables
* Understanding how use of a “standard wind-up” will make it possible to compare wind-ups

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Identify differences in wind-up construction and operation | No differences identified | Recognizes differences in construction or operation, but not both | Identifies differences in both operation and construction | Identifies multiple possible causes for an issue |
| B. Connect different wind-up designs with different modes of operation | No connections made | Recognizes that different designs may operate differently, but does not specify what type does what | Sorts designs according to how they operate | Explains why different kinds of wind-ups operate differently |
| C. Understand the need for a standard type of wind-up | No differences identified | Identifies differences among wind-up but does not seem aware of the need for a standard type | Suggest the need to standardize, but does not explain why | Connects standardization with the need for a “fair test” |

## Advance Preparation

* Collect a variety of wind-ups, with different wheel sizes, such as a wind-up with two large wheels, made from paper plates; a wind-ups with two plastic lids as wheels; a wind-up that has only one plastic lid; a small wind-up made from a tube rather than a cup, etc. See Advance Preparation for Lesson 2.

## Materials

* Wind-ups made in previous lessons
* Materials for making wind-ups, the same as for Lesson 2

## Procedure

## Differences among wind-ups (Whole class/ Individual – 30 min.) Display three or four different kinds of wind-ups, but do not operate them yet. Ask:

## What do you notice about each one? How are they similar? How are they different?

## If I wind it up and let it go, what do you think each one will do?

After they have made their predictions, test them by operating each type of wind-up. Then ask:

* *What differences did you notice in the way they operate?*
* *How does the design of a wind-up affect the way it moves?*

## Provide time for students to write their observations and conclusions in their notebooks.

Science Notebook

* What were the differences in the way the different wind-ups were made?
* What were the differences in the way the different wind-ups moved?
* How does the way a wind-up is made affect the way it moves?

## Finding and sorting variables (Whole class – 20 min.): List the differences that students have identified. Explain that each of the ways we can change a wind-up, such as wheel size, type of rubber band, or amount we wind it up, is what scientists call a variable. Any difference in the way it works – such as goes straight, goes in circles or spins in place – is also a variable. To keep these two kinds of variables separate, introduce the terms design variable – a change in how it was made; and performance variable – a change in what it did when we let it go. Help students sort the variables they have identified into these two categories: design variables and performance variables.

**Suggested breakpoint between periods**

1. Learning more about wind-ups (Whole class – 10 min.): Introduce the idea that to learn more about how wind-ups work, we will try to do some **experiments** on them. For example, we might come up with an experiment to answer the question “If I wind it up more times, how will that change how far it goes?” Ask:

* *What experiment could you do to answer that question?*

1. A standard design (whole class – 20 min.): Ask students to imagine what it would look like if the whole class did the experiment they have just designed:

* *If we wanted to do this experiment, what would happen if everyone was using a different kind of wind-up?*
* *What would go wrong if some of the wind-ups went in circles, some went straight and others didn’t go anywhere at all?*
* *What could we do to make it easier to learn from the experiment?*

Help students develop the idea that it would be much easier to draw conclusions if everyone in the class was working with the same kind of wind-up, which we might call a **standard design**.

* *What design variables should we keep the same in order for everyone to have a similar kind of wind-up?*

Ask the class to agree on a standard design, so everyone’s wind-up will work in a similar way. Make a list of the parts that should be kept the same. These should include the wheels, rubber bands, sticks, beads, and cups should be kept the same, in order to have a standard type of wind-up.

NOTE: In Lesson 6 students will make wind-ups with large (paper plate) wheels to compare to those with smaller wheels, so the standard design should use plastic lids as wheels.

1. Make, draw and label a new wind-up (Individual – 20 min.): Provide materials and time for each student to make a new wind-up based on the standard design. They should also make note of anything that did not work at first, and how they fixed it. Distribute the worksheet. Students complete this drawing, which will be used in Lesson 5.

NOTE: These notes will be used to write a Troubleshooting Guide in Lesson 5.

1. Draw and label your wind-up.

## Word Bank

Variable, design variable, performance variable, experiment, standard design, fair test

## Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Lesson 4: Draw and Label your Standard Wind-up

Draw the standard wind-up and label the parts:

What issues came up in getting your wind-up to work?

1.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 2. ­­­­­­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

3.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ 4. ­­­­­­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

What did you do about each issue?

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lesson 5: Exploring How a Wind-up Works   
& Writing a Troubleshooting Guide**

## **Essential Question**

How does a wind-up work?

## **Task**

Explaining wind-up operation, and using this knowledge to write a troubleshooting manual

## Standards

CCLS – ELA **Writing**: Text types and purposes; Production and distribution of writing; Presentation of Knowledge and Ideas **Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 4. Analyzing and interpreting data; 7. Engaging in argument from evidence; 8. Obtaining and evaluating information.  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 4. Energy and matter; 6. Structure and function  
**Disciplinary Core Ideas**: PS3: Energy; ETS1: Engineering Design

***Outcomes***

* Developing explanations of how the unwinding of the rubber band causes the motion of a wind-up
* Using knowledge of wind-up operation to write troubleshooting guides

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Explores how rubber band powers a wind-up | No explanation | Explanation does not include unwinding of the rubber band | Notices that rubber band gets twisted as stick is turned | Identifies untwisting of the rubber band as source for motion of wind-up |
| B. Create a troubleshooting guide | No connections made | Recognizes that different designs may operate differently, but does not specify what type does what | Sorts designs according to how they operate | Explains why different kinds of wind-ups operate differently |

## Advance Preparation

* Make a sample wind-up using the transparent cup.
* Try the wind-up experiments described in step 5 of Procedure.
* Become familiar with the sequence of events in wind-up operation, for example by reviewing the Teacher Notes for Lesson 5, p. 21, and/or the description in terms of energy concepts in the video at <http://www.citytechnology.org/node/2681>
* Post the Issues chart from Lesson 2 and the Troubleshooting chart from Lesson 3.

## Materials

* Materials for making wind-ups, as in Lesson 2
* Wind-ups made in previous lessons
* Transparent cups, short lengths of string

## Procedure

1. How can we see inside? (Whole class – 10 min.) Ask students what they have noticed about the way a wind-up works. Record their observations. Then ask:

* *What kind of information are we missing?*
* *How could we find out more?*

If they don’t come up with the idea, suggest that it would be useful to see inside the wind-up while it is operating. Ask:

* *How could we change the wind-up to make it possible to see inside?*

Students will likely suggest substituting a **transparent** cup for the **opaque** one they have been using.

1. Make a see-thru wind-up (Individual – 15 min.) Distribute transparent cups and other supplies for making wind-ups and provide time for students to make wind-ups using the transparent cups. If students have difficulty making the hole in the bottom of the transparent cup, suggest they use a push pin to get the hole started, and then enlarge it using the end of a skewer or ball point pen.
2. How a wind-up works (Whole class – 15 min.) Ask students to operate their see-thru wind-ups, and observe carefully what happens at each step.

* *What do you notice that is happening inside the cup as you wind up the stick?*
* *What do you think would happen if you replaced the rubber band by a piece of string?*

Students should be able to answer this last question immediately, but you can provide a length of string to each group in case students want to try this experiment.

* *When you let the stick go, what parts are turning, and what parts are not?*
* *What is making some of the parts turn*?
* *What do you think is keeping the other parts from turning?*

4. Observations about wind-ups (Individual – 10 min.) Provide time for students to record their observations and ideas about how wind-ups work. Some terms they can use in these descriptions are the **input** to a wind-up – the energy you put in by winding it up; and the **output** – themotion of the wind-up once it is released. In between, there are **energy transformations** involving both potential and kinetic energy. You may want to review these concepts briefly from Lesson 2.

Science Notebook

* What have you learned about how a wind-up works?
* Describe what happens as you wind up the stick.
* Describe what happens after you let the stick go.

**Suggested breakpoint between periods**

1. Wind-up Experiments (Small group/ whole class – 15 min.) Here are three simple experiments that the students can do to reveal more about how wind-ups work. Ask each group to do one of the experiments, record what they found, and then share the results with the rest of the class.
2. Two sticks: Replace the paper clip with a stick. The result is a stick on each side, instead of just on one side.

* *What happens?*
* *Why doesn’t it work?*
* *When the rubber band unwinds, what does it need to do, in order to make the wind-up go?*

1. One short stick: Replace the stick with a short stick that does not extend beyond the wheel.

* *What happens now?*
* *What does the stick have to do to allow the wind-up to go?*
* *Why does the stick need to touch the floor?*

1. Paper clip spins: Make it so the paper clip can spin freely against the wheel. The best way to do this is to slip the rubber band through a bead, to keep the paper clip away from the wheel.

* *What do you notice about the paper clip?*
* *What does the paper clip need to do to make the wind-up work?*
* *What’s preventing the paper clip from doing its job?*

1. Results of the Experiments (Whole class – 15 min.). Ask the groups that did each experiment to get together and prepare to report on what they found out and how they might make their wind-up work. Then have a class meeting. Allow the groups to demonstrate so all can see. Help them break down the entire sequence of steps that occurs from beginning to turn the stick to the wind-up traveling on its own.
2. Troubleshooting guide (Individual – 20 min.) Display the chart of Issues from Lesson 2 and the Troubleshooting Chart from Lesson 3. Based on knowing how wind-ups work, students should now have even more insight into how to troubleshoot a wind-up that doesn’t work. Distribute the worksheet. Ask each student to create a Troubleshooting Guide showing how to deal with each of the issues they have identified.

## Word Bank

opaque, transparent, transformation of energy, input, output

## Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_

Lesson 5: Wind-up Troubleshooting Guide

|  |  |
| --- | --- |
| Issue:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | |
| Cause: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | Fix:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

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| --- | --- |
| Issue:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | |
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## Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_

Lesson 5: Wind-up Troubleshooting Guide, Continued

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| --- | --- |
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| Cause: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | Fix:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

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| --- | --- |
| Issue:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | |
| Cause: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | Fix:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

**Lesson 6: Plan an Experiment on Wind-up Wheel Size**

## **Essential Question**

How can we find out the effect of wheel size on how a wind-up works?

## **Task**

Students design an experiment for exploring the effect of wheel size

## Standards

CCLS – ELA **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 3. Planning and carrying out investigations   
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function

***Outcomes***

* Predicting the effect of one variable on another
* Understanding that an experiment is needed to reveal how one variable affects another
* Planning an experiment, including methods for collecting and recording data

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Predict the effect of wheel size on wind-up operation | No prediction | Effects are predicted, but are not related to wheel size | Predicts how wheel size could affect one outcome: speed or distance | Predicts how wheel size could affect both speed and distance |
| B. Understand the need for an experiment to determine the effect of wheel size | Does not see need for an experiment | Suggests an experiment but does not justify its use | Maintains that an experiment will provide new knowledge | Explains how an experiment can provide evidence, which is more convincing than opinion |
| C. Plan an experiment to determine effect of wheel size | No plan | Plan does not include sorting data according to wheel size | Plans to compare data from wind-ups with two different wheel sizes | Plan includes a way of drawing conclusions from the data |

## Advance Preparation

* Make a new wind-up, similar to those in Lessons 4 & 5, but with paper saucer wheels instead of lids
* Make a chart showing the materials needed for the new wind-up

***Materials***

* Same materials as used in Lesson 4 for making a standard wind-up, but using paper plates instead of plastic lids for wheels.

***Procedure***

1. What difference does wheel size make? (Whole class – 20 min.) Display two wind-ups: one that uses plastic lids for wheels, as in Lessons 4 & 5; and another that is made similarly, except with paper saucers as wheels: Ask:

* *What difference do you think the size of the wheels will make in how these two wind-ups will go*? *Why do you think so?*
* *How can we find out?*

Students will probably offer their own opinions. Ask:

* *How can you really be sure?*
* *Different people might have different opinions. What can we do to decide whose opinion is right?*

Develop the idea of doing an **experiment** to answer this question. An experiment will provide **evidence** for one answer more than for another. By looking at evidence, we can all agree about what happens. Then ask:

* *What will we need to have in order to do this experiment?*

Students should realize that the will need to have two kinds of wind-up, in order to compare what they do. They already have the standard wind-ups from Lessons 4 & 5. Discuss what the other wind-up might look like:

* *How should the second wind-up be different from the first?*
* *What wheels should you use?*
* *What should you use for all the other parts?*

Reinforce the idea that to be a fair experiment, the wind-up they make must be the same as the one made in Lesson 4, except for the wheel size.

1. Making wind-ups with large wheels (Individual – 15 min.) Post a list of materials for this wind-up. Have students get materials and build wind-ups. Walk around the class to help any who have issues.
2. Planning the experiment (Whole class – 20 min.) Meet with the class to discuss how to conduct the experiment.

* *We will have two kinds of wind-ups to try out. What should we find out about each kind?*

If students haven’t already identified “distance traveled” as the performance variable, ask:

* *What would we need to do to measure speed? What would we have to do to measure distance traveled? Which would be easier to do?*
* *How many think the paper saucer wind-up will go farther? How many think the smaller wheel wind-up will go farther?*
* *What kind of evidence will we need to collect?*
* *How will you know how far each wind-up goes? How will you measure it?*
* *How can we keep track of our results, so we’ll know which kind of wind-up went each distance?*

Explain that whenever we measure something, and record the numbers we have measured, we call the results **data**. In order to organize the data, and see it all at once, it is helpful to put it in a chart called a **data table**. Based on the discussion, develop a class data table that the class can use to record distances measured for each type of wind-up.

## Word Bank

experiment, compare, opinion, evidence, distance, measure, data, data table, diameter

**Lesson 7: Experiment with Wheel Size**

## **Essential Question**

Which one goes farther: a wind-up with small wheels or one with large wheels?

## **Task**

Students conduct an experiment to investigate the effect of wheel size on distance traveled

## Standards

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

CCLS—Math  
**Math Practices**: MP2: Reason abstractly; MP6: Attend to precision; MP7: Look for and make use of structure  
**Measurement and Data:** 2.MD 1-4 Measure and estimate lengths; 2. MD 9&10; 3.MD 3&4 Represent and interpret data

NGSS   
**Scientific & Engineering Practices** 3. Planning and carrying out investigations; 4. Analyzing and interpreting data; 7. Engaging in argument from evidence; 8. Obtaining, evaluating and communicating information  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function; 7. Stability and change  
**Disciplinary Core Ideas**: PS2: Motion and stability: forces and interactions

***Outcomes***

* Collecting and recording data on distance traveled by two kinds of wind-ups
* Evaluating the experiment to decide if it was a fair test
* Drawing conclusions from the data about cause-and-effect relationships

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Collect and record distance data | Measurements are faulty or non-existent | Data is collected, but not recorded; or recorded data does not correspond to measurements | Minimal data is recorded according to wheel size | Numerous data points are collected and recorded according to wheel size |
| B. Evaluate an experiment to look for control of variables | No evaluation | Evaluation is attempted, but is inconclusive | Identifies some variables that were controlled or not | Explains how control of variables, or failure to control them, could affect the outcome |
| C. Draw conclusions from data | Conclusions are non-existent or unrelated to data | Conclusions are tentative or not expressed clearly | Conclusions are drawn and compared with predictions | Attempt is made to explain why independent variable affects dependent variable |

## Advance Preparation

* Post the Data Table developed in Lesson 6
* Photo copy the worksheet
* Conduct the experiment yourself
* Determine the spaces where students will be able to test their wind-ups. The space will probably need to be larger than a typical classroom; possibilities are a hallway, lunchroom or gym.

***Materials***

* Wind-ups made in Lesson 4, using plastic lids as wheels
* Wind-ups made in Lesson 6, using paper plates as wheels
* Materials to repair or make new wind-ups (same as lessons 4 & 6)

***Procedure***

1. Review of the plan for an experiment (Whole class – 10 min.). Review the plan for collecting data about the distance traveled by two kinds of wind-ups: those with big wheels and others with small wheels. Point out that a wind-up might go all the way across a classroom, and that there could be furniture in the way. Ask:

* *What would be a good place to test our wind-ups?*

Develop a plan for dividing the class into groups, and assigning each group a test area that will be big enough to get the full distance a wind-up can travel, and far enough apart so that the groups won’t get in each others’ way. Distribute the worksheets. Ask:

* + *How will you measure the distance traveled by each one?*
  + *Where will you record your data?*
  + *How many times should you test each wind-up?*
  + *If you’re looking for the effect of wheel size, what other variables should you try to keep the same?*

1. Conducting the experiment (Small groups – 30 min.). Circulate among the groups as students conduct their tests. Assist students in troubleshooting wind-ups that don’t work. Observe how students are making measurements and recording data, and raise questions as needed. .
2. Discussion of the results (Whole class – 10 min.) Ask students to share their data, and post the data, group by group, on the large data sheet. As students present their data, ask:

* *What differences did you notice between the wind-ups with small wheels and those with big wheels?*
* *What did the rest of you observe?*
* *Why didn’t everyone get exactly the same data? What could have been different from one wind-up or one trial to another?*

Develop the idea that it is not possible to run the same experiment exactly the same way twice. However, there are some differences that you can control:

* *How many times did you turn the stick before you tested your wind-up? Did you count? If not, how could the number of turns have affected your data?*
* *If we only want to know about the effect of wheel size, what should we do to try to keep anything else from affecting our results?*

Revisit the concept of a fair test: one in which we try to keep all the variables the same, except the ones we are trying to test.

* *In addition to number of turns, what are some other variables we should try to keep the same?*
* *Which one(s) should we change?*

## Word Bank

pattern, cause, effect, fair experiment, generalize

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Experiment on Effect of Wheel Size

|  |  |  |
| --- | --- | --- |
|  | Wind-up with small wheels | Wind-up with large wheels |
| **How far did this wind-up go?** | **How far did this wind-up go?** |
| Trial 1 |  |  |
| Trial 2 |  |  |
| Trial 3 |  |  |

What was the independent variable (the one you changed)? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

What was the dependent variable (the one that changed as a result)? \_\_\_\_\_\_\_\_\_

What does your data tell you about the effect of one variable on the other? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

How can you explain this effect? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**Lesson 8: Experiment with Number of Turns**

## **Essential Question**

How does the number of turns of the stick affect how far a wind-up travels?

## **Task**

Students design and conduct an experiment to investigate the effect of number of turn on distance traveled

## Standards

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

CCLS—Math  
**Math Practices**: MP2: Reason abstractly; MP6: Attend to precision; MP7: Look for and make use of structure  
**Measurement and Data:** 2. MD 9&10; 3.MD 3&4 Represent and interpret data

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 3. Planning and carrying out investigations; 4. Analyzing and interpreting data; 7. Engaging in argument from evidence; 8. Obtaining, evaluating and communicating information  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function; 7. Stability and change  
**Disciplinary Core Ideas**: PS3: Energy

***Outcomes***

* Collecting and recording data on distance traveled by wind-ups, using different wheel sizes and different numbers of turns
* Drawing conclusions from the data about cause-and-effect relationships
* Recognizing that more than one variable can affect the results of an experiment

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Collect and record distance data | Measurements are faulty or non-existent | Data is collected, but not recorded; or recorded data does not correspond to measurements | Minimal data is recorded according to wheel size | Numerous data points are collected and recorded according to wheel size |
| B. Draw conclusions from data | Conclusions are non-existent or unrelated to data | Conclusions are tentative or not expressed clearly | Conclusions are drawn and compared with predictions | Attempt is made to explain why independent variable affects dependent variable |
| C. Recognize the role of multiple variables | No recognition that more than one variable could affect results | Recognizes role of multiple variables, but not how they interact | Recognizes need to test each variable separately | Explains why both # of turns and wheel size affects results |

## Advance Preparation

* Photo a copy of the worksheet for each student, plus a few extra for the preliminary trials
* Prepare a large sheet of chart paper for collecting a classroom set of data. Divide it into four quarters:

|  |  |
| --- | --- |
| Small wheels – fewer turns | Small wheels – more turns |
| Large wheels – fewer turns | Large wheels – more turns |

* Conduct the experiment yourself

***Materials***

* Large- and small-wheel windups made in Lessons 4 & 6, and compared in Lesson 7
* Materials to repair or make new wind-ups (same as lessons 4 & 6)

***Procedure***

1. Planning an experiment on effect of number of turns (Whole class – 15 min.) Review what happened in Lessons 6 & 7. We did an experiment on how wheel size affects the distance traveled by a wind-up:

* *Besides wheel size, what other variables could affect distance?*

Students will probably remember that the number of turns of the stick could have an effect also. If both wheel size and number of turns was different, we couldn’t really draw a conclusion about the effect of either one. In this experiment, we will find out what difference the number of turns makes in how far a wind-up will go. Ask:

* *If the variable we want to test is number of turns, what should we do about wheel size?*

Students should realize that we should keep the wheel size the same, or else we won’t know what is causing any difference in distance traveled.

* *How many times should we wind a wind-up to make sure it will go*?

Get different opinions, then try one number (not too large) with the large wheel wind-up to see if it works. Ask students what number they think would work best. It should be enough to make the wind-up go a measurable distance, but small enough that it can be compared with a larger number of turns later. After the class has agreed on a number, ask for suggestions for this larger, second number:

* + *How many times should we wind it to make it go farther?*

Engage the class in selecting a second number of turns for everyone to use, at least 20 turns more than the first.

1. Preliminary testing of wind-ups (Small groups – 20 min.) Divide the class into an even number of small groups. Half of the groups will experiment with the large-wheel wind-up, half with the small-wheel wind-up. Distribute one worksheet per group. Ask each group to try out both of the agreed on number of turns on their type of wind-up (small- or large-wheel). They should circle the type of wind-up they used on table on the top of the worksheet, and enter the two numbers of turns (fewer and more) in the left column of the table at the center.

Science Notebook

* What have you learned about how the number of turns affects a wind-up?
* What issues came up in this experiment?
* How would you change the experiment, so we could learn more from it?

1. Discussion of preliminary tests (Whole class – 15 min.) Review the results of the experiment with all the groups:
   * *What did you find out?*
   * *What issues came up?*
   * *At what point should we start counting turns?*

The answer to this last question is not obvious, because the first few turns will often have no effect. . One idea would be to wind up the stick until it begins to resist, then let it unwind, and use that position as a starting point. This could also be an opportunity to revise the two numbers of turns, if they either too close to each other, both too small or both too large.

Another issue is **variation** in the data.

* *Even if you do the experiment exactly the same way, several times, what do you notice about the results?*
* *What could make it come out a little different each time?*
* *How many times should we repeat the experiment to get results we can trust?*
* *When we have more than one result, how should we combine them?*

Develop the idea that some factors, such as friction, are not very predictable, and it makes sense to do the experiment more than once and take an **average** of the results.

**Suggested breakpoint between periods**

1. Revising the experiment (Whole class – 10 min.): Based on the previous discussion, ask the class to agree on any changes in the way the experiment is conducted. These changes could include:

* Changing one or both of the numbers of turns (fewer and/or larger number)
* Deciding on a standard way to start counting turns
* Deciding on how many trials to do, and how to combine the data

1. Conducting the experiment (Small groups – 25 min.): Distribute a worksheet to each student. Each group should conduct the experiment with their wheel-size, based on the newly revised method of doing the experiment. Remind students how to fill in the worksheet.
2. Conclusions from the experiment (Whole class – 15 min.): Post the data chart for recording each of the four types of data: large wheels/ small wheels; more turns/ fewer turns. Collect all the data from all the groups, and enter the numbers on the chart. Ask:

* *What does this data tell us about the effect of wheel size on distance traveled?*
* *What does the data tell us about the effect number of turns on distance traveled?*
* *Why don’t we get the same exact data each time we do the same experiment?*
* *Why does turning the stick more make the wind-up go farther?*

In answering the last question, revisit the concept of energy:

* *What makes a wind-up go? Where does the energy come from?*
* *What happens to the amount of energy when you turn the stick more times?*
* *What happens to this energy when you release the stick?*
* *What does it take to make the wind-up go farther*

## Word Bank

Variation, average

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Experiment on Effect of Number of Turns

|  |  |
| --- | --- |
| Which wind-up did you test? (Circle one) | |
| Wind-up with small wheels | Wind-up with large wheels |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of turns of the stick** | **Distance the wind-up went** | | | |
| **Trial 1** | **Trial 2** | **Trial 3** | **Average** |
| Smaller number = \_\_\_\_\_ |  |  |  |  |
| Larger number = \_\_\_\_\_ |  |  |  |  |

What was the independent variable (the one you changed)? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

What was the dependent variable (the one that changed as a result)? \_\_\_\_\_\_\_\_\_

What does your data tell you about the effect of one variable on the other? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

How can you explain this effect? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lesson 9: Redesigning and Customizing Wind-ups**

## **Essential Question**

How can you design a wind-up that operates and looks the way you want?

## **Task**

Students explore different ways a wind-up could operate, and design a new one based on these ideas..

## Standards

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 6. Designing Solutions   
**Crosscutting Concepts:** 1. Patterns; 6. Structure and function   
**Disciplinary Core Ideas**: ETS1: Engineering Design

***Outcomes***

* Recognize multiple uses for a wind-up mechanism
* Design of a new rubber-band-powered device

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Recognize multiple uses for wind-up | No recognition | Recognizes that a wind-up could power more than one type of device | Identifies several different ways a wind-up mechanism could be used | Suggests additional variations for use of a wind-up |
| B. Design of a device that uses a wind-up mechanism | No design | Design is incomplete or unclear; or replicates an existing device | Design incorporates original features | Creative design that is substantially different from any that exist |

## Advance Preparation

Construct four wind-ups that are different from those students have already made:

* a four-wheeler
* a merry-go-round; and
* a wind-up that makes a moving picture

For instructions, view the three videos under Advance Preparation at   
<http://www.citytechnology.org/energy-system/9-redesign-and-decorate-wind-ups>

## Materials

* Materials for making wind-ups including different size paper plates and cylinders
* Craft materials: crayons, paints, markers, colored and plain paper, magazines for pictures, tissue paper, cellophane, google eyes, feathers, yarn, felt, foam stickers, craft sticks, ribbon, pipe cleaner, cocktail umbrella, tape, glue and scissors

***Procedure***

1. Uses for a wind-up mechanism (Whole class – 20 min.): Remind students about the wind-ups they have made, and ask them to think of other ways to use the same type of **mechanism**:

* *We have seen how a rubber band can make a wind-up go across the floor or table. What else could we use the same wind-up mechanism to do?*

Students may suggest holding the cup vertically, instead of laying it on the table horizontally, adding wheels, using a wind-up to tow a trailer, etc. Post all their ideas on chart paper. Ask the class how they would think about making each one, and post these ideas too. Then demonstrate the three new wind-ups you have made (see Advance Preparation): the four-wheeler, the merry-go-round and the movie machine. Ask students:

* *What additional ideas do you get from these?*
* *What would you use a wind-up mechanism for?*

Explain that students will soon have an opportunity to present their wind-ups to an audience (Lesson 12). They can use any of these new ideas for their wind-ups. Introduce the idea of **customizing**: making something look the way you like it to look. When you customize something, you are thinking not only about how it works, but also about how it looks. When something looks nice, it has **esthetic** appeal – the same goal we strive for in creating **art**. Ask:

* *What materials would we use to customize our devices?*

Collect ideas and chart them. Then present the craft materials you have available for them to use. Ask:

* *How could you use these materials in making a new wind-up device?*
* *What changes would you need to make in the basic wind-up design to make it work and look the way you want?*

For example, if a student decides to use a wind-up mechanism to make a movie machine, they may need to use large wheels and a larger cylinder to separate the plates, so the moving pictures can fit around the cylinder.

1. Design your new device (Individual – 20 min.): Students develop their ideas and record them in their Science Notebooks.

Science Notebook

* Describe what you would like your new wind-up device to do
* Make a diagram showing how you will put it together.
* Explain how it will work

1. Sharing ideas: (Whole class – 10 min.) Ask students to share their ideas briefly, including any issues they have run into. Ask the class if they have suggestions about how to resolve these issues.

## Word Bank

mechanism, customize, spin, roll, animate, vertical , horizontal, esthetic, art

**Lesson 10: Make a Wind-up for the Show**

## **Essential Question**

How can you make the wind-up you have designed in Lesson 9?

## **Task**

Students make and troubleshoot the wind-ups they have designed, and explain how a wind-up uses energy and friction.

## Standards

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 6. Designing Solutions **Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function; 7. Stability and change  
**Disciplinary Core Ideas**: PS2: Motion and stability: forces and interactions; PS3: Energy; ETS1: Engineering Design

***Outcomes***

* Make and troubleshoot a new wind-up
* Explain how a wind-up works

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Make and troubleshoot a new wind-up | Nothing is made | Wind-up does not work | Creates and troubleshoots basic design | Creative design is executed with flair |
| B. Explains how a wind-up works | No explanation | Explanation refers to “energy” but is vague about its transformations | Identifies transformations of energy from winding up to release of wind-up | (3) + provides examples of how friction can be helpful and not helpful |

## Advance Preparation

* Photocopy "Assessment: How a Wind-up Works" p. 54

## Materials

* Wind-ups begun by students in Lesson 9
* Same materials as were available in Lesson 9

***Procedure***

## Overview: (Whole class – 10 min.) Remind students that there will be a Wind-up Show in the last lesson. They should have already designed and perhaps begun making the wind-ups they will make for the show. Today they will complete their wind-ups. Invite a few students to share their plans for completing them.

1. Completing the wind-ups: (Individual – 30 min.) Distribute any partially completed wind-ups and provide materials for completing them. Ask students to keep track of each step in the process in their Science Notebooks. They will use this information in Lesson 11 when they write Instruction Manuals for making wind-ups.

Science Notebook

* Describe each step in the process of making your wind-up
* Make a diagram showing what it looks like at each step.

1. Assessment: How a Wind-up Works (Individual – 10 min.) Provide an assessment sheet to each student. It provides a way for them to think about and describe what they have learned about wind-up operation.

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date:\_\_\_\_\_\_\_\_\_\_\_\_\_

Assessment: How a Wind-up Works

1. How does energy get into the Wind-Up? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. How is the energy stored in a wind-up? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. What happens to the energy when you let the Wind-Up go? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Describe where your Wind-Up *needs friction* in order to work:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Describe where friction *can* *prevent* your Wind-Up from working:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**Lesson 11: How to Make My Wind-up**

## **Essential Question**

How can I tell someone else how to make the same kind of wind-up I made?

## **Task**

Students create illustrated instruction manuals that show step-by-step how to make the wind-up they have made.

## Standards

CCLS – ELA **Writing**: Text types and purposes; Production and distribution of writing; Research to build and present knowledge  
**Language**: Vocabulary acquisition and use

NGSS   
**Scientific & Engineering Practices** 1. Asking questions and defining problems; 6. Designing Solutions; 8. Obtaining, evaluating and communicating information  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function  
**Disciplinary Core Ideas**: ETS1: Engineering Design

***Outcomes***

* Create an Instruction manual
* Test the manual and revise it based on the outcome

## Assessment

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| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Create an instruction manual | No steps are shown | Manual shows a few steps, but is incomplete | Manual shows all the steps, but is sometimes unclear | Complete manual, easy to follow |
| B. Test and revise instruction manual | No test of manual | Manual is tested, but results are inconclusive | Identifies issues in the manual | Identifies issues and revises manual to address them |

## Advance Preparation

* Collect instruction manuals from furniture, electronics, Legos™, etc.
* Photo copy the worksheet: “Instruction Manual for Making a Wind-up” pp. 27, 28.

## Materials

* Wind-ups already made by students
* Materials for making wind-ups, for use as spare parts.

## Procedure

1. What is an instruction manual? (Whole class – 15 min.): Students may already be familiar with How-to Books. Meet with students to discuss what an instruction manual is and how it can be used:

* *What is a “How-to” book?*
* *Who is it for?*
* *When have you used one?*
* *What did it help you to do?*

Show them some instructional manuals you have collected. Ask if anyone has used such a book and if so to describe how it was or was not useful.

* *How could you create a How-to book showing how to make a wind-up?*

Explain that an engineering term for a How-to Book is an **Instruction Manual**.

What should an instruction manual have? Discuss how an instruction manual could provide information:

* *Why would you want one?*
* *What should it include?*

Develop the idea that someone else might want to make what you made, and you might not be around to show them. Your Instruction Manual will tell them how to make one. Or maybe, you might want to make one yourself at a later date, but by then you might have forgotten how to do it. Your Instruction Manual will remind you about what to do.

1. Writing instruction manuals (Individual -- 35 min.) Develop the idea that – like instruction manuals they have seen – their manuals should include drawings as well as words. If necessary, remind students about the drawing techniques they developed in Lesson 4. Provide time for each student to write his or her own Instruction Manual, using the Worksheet.

**Suggested breakpoint between periods**

1. Testing and revising instruction manuals (Small groups – 30 min.) After students have finished writing their manuals, demonstrate how to test an Instruction Manual. Select an instruction that is vague, such as “Make a hole in the cup,” and deliberately misinterpret it; for example, by making the hole on the side of the cup rather than the end. Ask students:

* *What do you think is the problem with this instruction?*
* *How could it be changed to make it clearer?*
* *What could happen if someone tries to follow an instruction that does not give enough information?*

Then ask students to exchange manuals in their groups, and test them to see if they give all the information that’s needed. Have them meet with one another to give suggestions for improvement,

1. Revising instruction manuals (Individual – 20 min.) Ask students to revise their instruction manuals to provide all the information that is needed. This could be a homework assignment.

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Lesson 11: Instruction Manual for Making a Wind-up

Materials I used (materials list)

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Steps to Make my Wind-up

Number each step. Use more pages if necessary

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Lesson 11: Instruction Manual for Making a Wind-up, continued

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**Lesson 12: The Wind-up Show**

## **Essential Question**

How well can you present your work and respond to questions about it?

## **Task**

Present and discuss wind-ups and instruction manuals

## Standards

CCLS – ELA **Writing**: Text types and purposes; Research to build and present knowledge  
**Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS  
**Scientific & Engineering Practices** 8. Obtaining, evaluating and communicating information.  
**Crosscutting Concepts:** 1. Patterns; 2. Cause and effect: mechanism and prediction; 6. Structure and function **Disciplinary Core Ideas:** ETS1: Engineering Design

## Outcomes

Understanding is enhanced through presentation and discussion

## Assessment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| Present the wind-ups to an audience | No presentation | Presentation is unclear or incomplete; can’t articulate how it works or what troubleshooting was done | Demonstration of the wind-up including description of how it works, troubleshooting and instruction manual | (3) + how it could be improved |

## Advance Preparation

* Arrange for space and if possible an audience from outside to attend presentations

## Materials

* Wind-ups and instruction manuals made by students
* Charts and tables showing design process and outcomes

## Procedure

1. **1. Presenting wind-ups** (Whole class – 100 min.) Provide a format and audience for students to present their work. The presentation should include notebooks and worksheets, as well as finished products. The show could take any of several forms:

* **Classroom presentation**: Each group demonstrates their pop-up book to the class. The class has to guess what it represents and how it will move when the input is operated. Students should also share the issues they encountered and what they did to solve them.
* **Bulletin board or poster display**: Pop-ups can be attached to poster boards or bulletin boards. By using push pins strategically – for example, at the corners – you can avoid interfering with the mechanism, allowing viewers to try them out to see how they work. The display should also include diagrams and other records of the design process.
* **Museum table**: For Parent-teacher Conferences, Open School Night, or other community events, the pop-ups can be displayed loose on tables with signs inviting viewers to guess what they will do and then test them.
* **Invention Convention:** Stage a science-fair style event, to give students an opportunity to explain their pop-ups to parents and other visitors.

**Glossary**

**Animate:** Make a series of pictures that appear to be moving when you see them quickly

**Art:** Creative product that people find pleasing

**Average:** A single number that represents the value of a group of numbers; it is found by adding the numbers in the group together and dividing by how many are in the group

**Cause:** What makes something else happen

**Compare:** Look at two things together and look for similarities and differences

**Customize:** Make something your own by adding features that you especially like

**Data:** Record of measurements you made as part of an experiment

**Data table:** A graphic organizer for presenting data, so it is easy to find the patterns

**Design variable:** Something you can change in the way you design something, such as the wheel size of a wind-up

**Diameter:** The longest distance you can measure across a circle

**Distance:** How far it is from one place to another

**Effect:** What happens as a result of a cause

**Elastic energy:** The energy stored in a material that can stretch and return to its original shape, such as a rubber band or balloon

**Energy:** A quantity that can take many different forms, but that can neither be created nor destroyed

**Esthetic:** Pleasing to the senses

**Evidence:** Information that supports a claim

**Experiment:** A method of creating new information, using evidence

**Fair experiment:** An experiment that can show cause-and-effect, by letting only one variable change at a time

**Fair test:** A fair experiment

**Fix:** Correct a problem that is causing something not to work

**Friction:** Resistance to motion of one part against another, often caused by rubbing between them

**Generalize:** Suggest how one or a few examples can tell you about many more situations

**Horizontal:** Laying down; parallel to the ground

**Input:** The action you have to take to operate a system

**Instruction manual:** A book that tells you how to do or make something

**Kinetic energy:** Energy carried by moving things

**Measure:** Describe a quantity by a number

**Mechanism:** A device that has moving parts

**Opaque:** Describes something you can’t see through

**Opinion:** One person’s idea, often not supported by evidence

**Output:** The result of applying an input to a system

**Pattern:** Repeating set of elements

**Performance variable:** Something that you expect to change as a result of changing a design variable, such as distance traveled as a result of changing wheel size

**Potential energy:** Energy that is stored for later use, such as the elastic energy stored in a rubber band

**Roll:** Move by rotating along a surface, such as a wheel on a cart

**Spin:** Move by rotating in the air, such as a top or yo-yo

**Standard design:** A basic design that everyone makes, so it can be compared with other designs

**Stored energy:** Potential energy

**Transformation of energy:** Process of changing energy from one form to another, such as potential to kinetic or vice versa

**Transparent:** Describes something you can see through; opposite of opaque

**Troubleshooting:** Identifying an issue and its cause, in order to fix it

**Variable:** A property that changes in the course of an experiment

**Variation:** Differences in the data, when the same experiment is done more than once

**Vertical:** Standing up; perpendicular to the ground

**Wind-up:** A device that is powered by the energy stored in a rubber band