**EnerJeeps (Grades 4-5)**

Teacher’s Guide

Overview

This unit develops concepts of energy and electricity through design, building and testing of toy electric cars. Students first learn to connect motors to batteries, and then to control these circuits with homemade switches. To understand and troubleshoot their circuits, they develop strategies for making diagrams using standard symbols that everyone in the class can agree on. Next they design, make and test simple cars that can be powered by gravity or pushing, and roll freely enough to overcome friction. Subsequently, they add motors to their cars and connect a wheel to the motor. This wheel drives the car by direct contact with the ground or by rubbing on one of the car's wheels. They learn and apply troubleshooting techniques, and write troubleshooting guides and instruction manuals for fixing and making their cars. They then explore drive systems, and make another car using a different drive system – powered either by a belt-and-pulley system or a propeller. Finally, they develop circuits for adding lights and horns to their cars, write instruction manuals for making these, and present their cars and writing to an audience.

Common Core Learning Standards for ELA

Common Core Writing Standards 4-5

**Text Types and purposes**

2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization and analysis of content.

**Production and Distribution of writing**

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

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 through investigation of different aspects of a topic.

Common Core Speaking and Listening Standards 4-5

**Comprehension and Collaboration**

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

**Presentation of Knowledge and Ideas**

4. Report on a topic, sequencing ideas logically and using appropriate facts and relevant, descriptive details to support main ideas or themes.

Language

**Vocabulary acquisition and use**

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

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

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. **Scale, proportion and quantity:** The concept of scale builds from the early grades as an essential element of understanding phenomena. Young children can begin understanding scale with objects, space and time related to their world and with scale models and maps.
4. **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. Starting in the earliest grades, students should be asked to 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.
5. **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.

**Core Idea PS4: Waves and their Applications in Technologies for Information Transfer**Electromagnetic waves can be detected over a wide range of frequencies, of which the visible spectrum is just a small part. Modern communication systems are based on the use of electromagnetic waves, including light waves, radio waves, microwaves and infrared.

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

**Core Idea ETS1: Engineering Design**Engineering design begins with the identification of a problem and the specification of clear goals that the final product or system must meet, while contending with a variety of limitation, or constraints, that place restrictions on a design. Models allow the designer to better understand the features of a design problem, visualize elements of a possible solution and predict a design/s performance. Because there is always more than one possible solution to a problem, it is useful to compare designs, test them and compare their strengths and weaknesses. Selection of a design often requires making trade-offs among competing criteria.

**Core Idea ETS2: Links among Engineering, Technology and Society**Advances in science, engineering and technology have had profound effects on human society, which can change significantly when new technologies are introduced, with both desired effects and unexpected outcomes.

Curriculum Map

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Summary** | **Approx. time (min.)** | **Vocabulary** | **Homework** | **Assessment Methods** |
| 1 | **Turn a Motor on** | Complete a circuit including a battery and motor, then reverse the motor direction. Make a battery holder. | 90 | Electric circuit, battery, source, electrons, model, current, voltage, complete circuit, electric motor, electrical energy, chemical energy, kinetic energy, direction of motion, rotation, clockwise, counterclockwise, load, input, output, conductor, insulator, lead, Motor, shaft, battery holder, | HW: Switch Hunt | Observation of what students make, discussion, student drawings, diagrams, and writing |
| 2 | **Make a Switch** | Make a switch, and then complete a circuit including a battery a motor and the switch. | 90 | switch, push-button switch, rotary switch, slide switch, toggle switch, pull-chain switch, control, contact, connector, open circuit, closed circuit. | Extension: Make other types of switches | Observation of what students make, discussion, student drawings, diagrams, and writing |
| 3 | **Let’s Roll** | Make a car platform that rolls easily and straight. | 90 | parallel, axle, body, friction, skewer, bearing, construction manual, troubleshooting guide, issue, fix. |  | Observation of what students make, discussion, student drawings, diagrams, and writing |
| 4 | **Make a Propeller-drive Car** | Design and make a propeller-drive car. | 45 | design, propeller-drive |  | Observation of what students make, discussion, student drawings, diagrams, and writing |
| 5 | **Troubleshoot and Redesign a Propeller-drive Car** | Troubleshoot and redesign a propeller-drive car so it runs well. Write a Troubleshooting Guide. | 45 | redesign, plan, troubleshoot, Troubleshooting Guide |  | Observation of what students make, discussion, student drawings, diagrams, and writing - Troubleshooting Guide |
| 6 | **How to Build a Propeller-drive Car** | Make an instruction manual for how to make a propeller-drive car. | 45 | feedback, instruction manual |  | Observation of what students make, discussion, student drawings, diagrams, and writing - Instruction Manual |
| 7 | **Add Lights to your Car** | Make a parallel circuit and install headlights for the car | 90 | Parallel circuit, series circuit |  | Observation of what students make, discussion, student drawings, diagrams, and writing |

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| **Lesson** | **Title** | **Summary** | **Approx. time (min.)** | **Vocabulary** | **Homework** | **Assessment Methods** |
| 8 | **Preparations for the Auto Show** | Make finishing touches & write instruction manual for the car (HW) | 45 |  |  | Observation of what students make, student drawings, diagrams, and writing |
| 9 | **The Auto Show** | Present the cars to an audience | 45 |  |  | Student presentations |
| Extension 1 | **Make a Direct-drive Car** | Learn about and use a direct-drive system in a car, then troubleshoot so it works well and write a brief troubleshooting guide. | 90 | direct-drive |  | Observation of what students make, discussion, student drawings, diagrams, and writing - Troubleshooting Guide |
| Extension 2 | **Make a Friction-drive Car** | Learn about and use a friction-drive system in a car, then troubleshoot so it works well and write a brief troubleshooting guide. | 90 | friction-drive |  | Observation of what students make, discussion, student drawings, diagrams, and writing - Troubleshooting Guide |
| Extension 3 | **Make a Belt-drive Car** | Learn about and use a belt-drive system in a car, then troubleshoot so it works well and write a brief troubleshooting guide. | 90 | belt-drive |  | Observation of what students make, discussion, student drawings, diagrams, and writing - Troubleshooting Guide |
| Extension 4 | **Enhance a Car with Horn & Reversing Switch** | Add a push-button horn circuit and reversing switch to any car. | 90 | reversing switch, parallel circuit, series circuit |  | Observation of what students make, discussion, student drawings, diagrams, and writing |

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| --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Standards alignment** | | | |
| **CCLS -- ELA** | **NGSS – Scientific & Engineering Practices** | **NGSS – Cross-cutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 1 | **Turn a Motor on** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| 2 | **Make a Switch** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| 3 | **Let’s Roll** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| 4 | **Make a Propeller-drive Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |

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| **Lesson** | **Title** | **Standards alignment** | | | |
| **CCLS -- ELA** | **NGSS – Scientific & Engineering Practices** | **NGSS – Cross-cutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 5 | **Troubleshoot and Redesign a Propeller-drive Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| 6 | **How to Build a Propeller-drive Car** | **Writing**: Text types and purposes; Production and distribution of writing; Research to build and present knowledge **Speaking & Listening**: Comprehension and collaboration **Language**: Vocabulary acquisition and u | 2. Developing and using models 8. Obtaining, evaluating, & communicating information | 4. Systems and system models; | ETS1: Engineering Design |
| 7 | **Add Lights to your Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| 8 | **Preparations for the Auto Show** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction.  4. Systems and system models  5. Energy and matter: flows, cycles and conservation  6. Structure and function | ETS1: Engineering Design |

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| --- | --- | --- | --- | --- | --- |
| **Lesson** | **Title** | **Standards alignment** | | | |
| **CCLS -- ELA** | **NGSS – Scientific & Engineering Practices** | **NGSS – Cross-cutting Concepts** | **NGSS – Disciplinary Core Ideas** |
| 9 | **The Auto Show** | **Speaking & Listening**: Comprehension and collaboration | 8. Obtaining, evaluating, & communicating information | 2. Cause and effect: mechanism and prediction  4. Systems and system models 6. Structure and function | ETS1: Engineering Design |
| Extension 1 | **Make a Direct-drive Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction  4. Systems and system models 5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| Extension 2 | **Make a Friction-drive Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction  4. Systems and system models 5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  ETS1: Engineering Design |
| Extension 3 | **Make a Belt-drive Car** | **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  2. Developing and using models 3. Planning and carrying out investigations  4. Analyzing and interpreting data 6. Constructing explanations and designing solutions  7. Engaging in argument from evidence 8. Obtaining, evaluating, & communicating information | 1. Patterns 2. Cause and effect: mechanism and prediction  4. Systems and system models 5. Energy and matter: flows, cycles and conservation  6. Structure and function | PS2: Motion and stability: forces and interactions PS3: Energy  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 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**

**\*\*Homework**

**\*\*Extensions**

Overview of Basic concepts

**Energy** is needed to make things happen, such as getting something to move, light up, or make noise. Energy can take many forms. Types include energy of sound, light, heat, position and motion; as well as elastic, chemical, magnetic and electrical energy. Energy can’t be created or destroyed, but it can be changed from one form to another. A **battery** stores energy in chemical form. Whenever the battery is part of a complete circuit, some of this energy changes to electrical energy. Electric energy is versatile, because it can be converted to many other forms. For example, a **motor** changes electric energy to kinetic energy; a **lamp** changes it to light energy, and a **buzzer** or **speaker** changes it to sound energy. You can’t see or hear electric energy at work, until it changes to motion, light or sound. Anything that changes electrical energy to some other form is called a **load**. Motors, lamps, buzzers, speakers, and toasters are all examples of loads. The opposite of a load is a **source**: it changes energy from some other form into electrical energy. Examples of sources are generators, solar cells and batteries.

A **circuit** is a **system** that includes a source, a load and **conductors** that transfer electrical energy fromone to the other and back again. Systems can be difficult to understand, because they involve pieces or **subsystems** that interact to function together. To make a system easier to understand, it is useful to construct a **model** that shows the way the parts interact without confusing details. A type of model that can represent a circuit is a **circuit diagram**, which uses **standard symbols** and connection rules to make the structure clear. A circuit diagram can be very helpful for troubleshooting or explaining a circuit, or for designing a new one.

A **control** governs the flow of energy. Examples of a control are a faucet, the knob on a stove that controls the flow of gas, or the button on an umbrella that releases the spring, allowing the umbrella to pop open. A control that governs the flow of electricity in a circuit is called a **switch**. Nearly every circuit has a switch of some kind, so that it is not always ON. Some switches are **manual –** a person turns them ON or OFF intentionally – while others are **hidden** or **automatic**, because they are operated by some other action. An ordinary light switch, push button and pull chain are examples of manual switches. Automatic switches are found in alarms, voice-operated devices, refrigerators, car doors and “tickle-me” toys.

Teacher Notes on each Lesson

Lesson 1: Turn a Motor On

The Penguin Race™ Toy

The toy consists of a bunch of penguins, a slide and a motorized escalator that lifts the penguins to the top of the slide, so they can go back down again. Besides being fascinating to watch, this toy provides an excellent model for understanding how an electric circuit works. The penguins are like the electrons, which account for the flow of electricity in a circuit. The escalator lifts them up to a place where they have enough energy to travel down the slide by gravity. It is like the battery in a circuit, which gives the electrons an “energy kick” that is enough for them to travel on their own through the rest of the circuit. While traveling down the slide, the penguins speed up, but then stop when they hit the bottom. In a circuit, the electrons lose their energy in other ways: they may make a bulb light up, create a sound in a buzzer or make a motor turn.

Two basic circuit concepts are current and voltage. The amount of **current** counts the number of electrons that are flowing. In the toy model of a circuit, you could increase the current by adding penguins. If there were too many penguins to fit in the track, you would have to make it wider to accommodate them. Similarly, a wire may need to be bigger to contain more current. The reason an automotive jumper cable or battery cable is so fat is that it takes a lot of current to start a car.

**Voltage** is a measure of how much energy kick the battery gives each electron as it passes through. The analogy to the battery in the toy model is the escalator. More voltage would correspond to a taller escalator, which would raise the penguins higher, and therefore give them more energy each time they went through.

The penguins make a **complete circuit**, because they have to return to the escalator on each go round to get another energy boost. Similarly, the electrons in a circuit have to return to the battery to get the boost they will need to keep running the motor. An analogy is often made between electric current and the flow of water, but this can be misleading, because in most water systems, we don’t see the return flow. For example, when you turn on a faucet, you see the water go down the drain, but it’s hard to visualize the entire water cycle that brings it back. The penguin toy makes it easier to understand an electric circuit, because it’s obvious that the penguins have to get back to the beginning of the escalator to the get the energy they’ll need to go down the slide again.

Turning on a motor

One wire from the motor has to touch the (+) side of the battery, and the other wire has to touch the (—) side. It doesn’t matter which wire is touching which terminal – the motor should come on either way (see next paragraph).

Reversing the connections between the motor and the battery

When you reverse the way the motor is attached to the battery (red to “—" instead of red to “+”), the motor will turn in the opposite direction. It can be hard to see which way the motor is turning, so it is helpful to add a little piece of tape to the shaft. The direction it is rotating – clockwise or counterclockwise – should be apparent from watching closely as it just begins to turn. Whether it is going clockwise or counterclockwise depends on your point of view. Clockwise viewed from one end is counterclockwise viewed from the other end.

Conductors and insulators

Some materials allow electricity to flow, while others don’t. Those that do allow flow are called **conductors** and those that don’t are **insulators**. All metals are conductors, and nearly all other materials are insulators.

Making a battery holder for an AA battery

Students may want to wire their motors to batteries and let them run for a while, without continuing to hold them. Here is a method for making a battery holder to which you can attach wires from a motor (or other wires) that will hold them indefinitely.

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Lesson 2: Make a Switch

What is a switch?

A switch is a device that can turn the flow of electrical current ON or OFF. It is an example of a **control**, which is a more general category of devices that can interrupt or allow the flow of energy, not necessarily electrical. Examples of controls are a water faucet, toilet handle, drain plug, stove control knob, mouse trap trigger and the umbrella release button. If a circuit didn’t have a switch, it would be like a sink without a faucet – either on or off all the time.

Conductors and insulators

Some materials allow electricity to flow, while others don’t. Those that do allow flow are called **conductors** and those that don’t are **insulators**. All metals are conductors, and nearly all other materials -- such as plastic, paper, cloth and cardboard -- are insulators.

What a switch needs

The basic requirements of a switch are two **contacts**, a way of attaching or detaching them and a connection to each contact that puts the switch inside the circuit. Both contacts and the connections to them have to be made of conductors, or current won’t flow through them. The switch has to interrupt the circuit when it is OFF, and connect the battery to the load (LED or buzzer) when it is ON. When the switch interrupts the circuit, the circuit is **open** and no current can flow. When the switch connects the circuit, it is **closed**, allowing current to flow.

**Ideas for making sample switches:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Type** | **Materials** | **How to make it** | |
| Push-button | Two paper fasteners, cardstock or cardboard | Attach the fasteners so that the leg of one can be pushed down to touch the head of the other, and so this same leg will spring back up when released. | pushbutton.jpg |
| Rotary | Two paper fasteners, cardstock or cardboard | Push both fasteners through the cardstock, about an inch apart. Keep one leg of one fastener on top. Rotate this leg so it is touching the top of the other fastener to turn the circuit on, and away to turn it off. | Rotary Switch.jpg |
| Slide | Three paper fasteners, cardstock or cardboard | Cut a slot for one paper fastener, and poke holes for the other two. Mount two paper fasteners through the holes with heads up, and mount the third though the slot with both legs up. The legs turn the circuit ON by touching the two heads, and OFF by sliding away from them. | slide.jpg |
| Toggle | Bulldog clip, two paper fasteners, cardstock or cardboard | Mount the paper fasteners about a half inch apart, and place the bulldog clip so its handle can touch both fasteners. Use the snap action of the bulldog clip handle turn the circuit ON and OFF. | toggle.jpg |

Troubleshooting circuits with switches

The diagram below shows- a simple circuit with a battery, a motor and a push button switch; and three connections between them, labeled A, B and C.



If the circuit is attached as shown in the diagram, and the motor doesn’t turn on when the switch is closed, there are five possible **causes** for the trouble. The table below shows how to **test** for each one, and how to **fix** it:

|  |  |  |
| --- | --- | --- |
| **Cause** | **Test** | **Fix** |
| Battery or motor is bad | Attach motor directly to battery; if motor still won’t turn on, either motor or battery is bad | Try a new battery. If motor now comes on, old battery was bad. If motor still doesn’t turn on, replace motor. |
| Bad connection at A, B or C | Squeeze each connection in turn. If switch now operates motor, the connection you were squeezing was bad. | Re-do connection, making sure metal is touching metal. |

Short circuits

A “short circuit” is a conductor that connects two points that do not appear to be connected, and should not be. There are two common types of short circuits. The most serious type involves a switch that is connected across the battery, as in the drawing below, left. The two dashed lines show the wires that are reversed, not shown as dashed compared with the correct circuit, which is shown on the further down for comparison. This looks similar to the circuit shown above, and it even appears to work, but it has a basic flaw!



Switch short circuits battery when closed

The switch appears to control the MOTOR, because pushing it down will turn the MOTOR off, and releasing it will turn the MOTOR ON. However, this is the reverse of the way the switch should work. The problem is that the switch is actually ON when the MOTOR goes off, and vice versa. The diagram on the right uses symbols to show the problem more clearly. Lesson 3 develops electrical symbols and diagrams.

When the switch is closed, current flows from one side of the battery to the other with nothing in between. The current bypasses the MOTOR completely, because the current follows the path of least resistance. When the switch is open, it allows the battery to supply the MOTOR normally. If the switch is left closed for very long, the battery will first get warm and then soon go dead.

For comparison, the drawing and diagram below show the circuit that operates correctly.



Switch interrupts circuit when open, turns LED ON when closed

This second circuit works correctly, because the switch interrupts the current when it is open, and allows current to flow from the battery to the MOTOR and back when closed. In the first case, the, MOTOR and switch are all said to be in **parallel**, because current can flow through either one if the other is removed. In the second case, the switch and MOTOR are in **series**, because current has to flow through one to get the other. Lesson 4 develops series and parallel circuits.

Another type of short circuit can occur within a switch. In this case, a switch that appears to be open is actually never open due to the short circuit, because the two metal contacts are always touching, even when they don’t seem to be. The drawing below shows one way this can happen. The rotary switch appears to be open until you look underneath. The two paper fasteners are actually touching! Fortunately, the solution is very simple – just turn the legs a little, so they no longer touch.

  
Rotary switch, which appears to be open, but is actually closed due to a short circuit underneath.

The table below summarizes the kinds of things that can go wrong in a circuit with a switch, and what to do about each one:

|  |  |  |
| --- | --- | --- |
| **Issue** | **Cause** | **Fix** |
| Load never turns ON | Load or battery is bad | Replace load or battery |
| At least one connections is bad | Re-do connection, and secure with tape or rubber band |
| Load never turns OFF | Switch has short circuit | Separate contacts so they don’t touch |
| Load turns on when switch is OFF, and *vice versa*; battery gets warm | Switch is connected across battery, and can’t interrupt circuit | Rewire circuit so switch can interrupt current path |

Lesson 3: Let's Roll

The table below shows how to address a variety of issues that can come up in making cars. Do not share any of these ideas directly with students. Provide just enough information to prevent frustration. The best way to do this is to ask questions, such as, “What should be able to turn?” Each issue may have more than one possible cause, so multiple causes are listed for some of the issues, as well as a fix for each one.

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Wheels won’t turn | Wheels are fixed to axles and axles are fixed to body | Use straws or paper fasteners to allow axles to rotate freely |
| Wheels are rubbing against body or against straw | Move wheels outwards on axle, further away from body |
| Wheels come off | Wheels free to slide on axles | Use a little clay, tape or rubber bands at ends of axles to stop wheels from leaving |
| Wheels turn a little, then stop | Wheels have burrs (high spots) | Use nail file or abrasive pad to file off high spots |
| Car goes slower than others | Too much friction | Use straws or paper fasteners to allow wheels to turn more freely |
| Too much weight | Reduce amount of material or use lighter materials |
| Car does not go as far as others | Too little weight | Add weights, such as steel washers |
| Car bounces or vibrates as it goes down ramp | Axle is bent | Replace axle with a straight skewer |
| Car turns rather than going straight | Axles are not parallel | Reposition axles to make them parallel |
| More friction on one side | Check to see that wheels can turn equally freely on both sides; if not , reduce friction on slow side |

Lesson 4: Make a Propeller-drive Car

Lesson5. Troubleshoot and Redesign a Propeller-drive Car

How does a propeller-drive car work? Newton's third law of motion says for every action there is an equal and opposite reaction. For the propeller car: the action = a spinning propeller pushes air on one direction; reaction = the propeller and all attached to it are moved in the opposite direction of the air that the propeller pushed.

This is not obvious so students need the opportunity to raise their own examples as well as what they think are counter examples. How hard we push back when we walk or run becomes more clear when on a slippery surface, or on skates. What about when we throw a ball? Well, if our feet are firmly planted and don't slip, then the earth is pushed ever so slightly in the opposite direction. If, however you throw forward from a skate board, the skate board, and you, will move slightly backward. Try this with a bowling ball and the reaction will be much greater.

Making the propeller car. The propeller-drive car is easy to make, but hard to get to work. It’s easy to make because it consists of the free-rolling car from Lesson 3, with a motor, propeller, battery and switch mounted on top. It’s hard to get it working because the air flow is not powerful enough to overcome much friction. Also, the propeller needs to be mounted high off the ground, so it won’t scrape, which makes it harder to make the vehicle stable against tipping over. Here is a troubleshooting guide for your use. Do not share this directly with the students!

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Motor & propeller won’t turn even when motor & propeller are removed from car | Connections are bad – metal surfaces aren’t touching | Review how to make connections – see “Connecting to an AA battery” under Troubleshooting, Lesson 3 |
| Switch not working | Review requirements for a switch & types of switches, Troubleshooting, Lesson 2. |
| Battery is dead | Test battery by connecting a motor that you know is good directly against the battery terminals. If the good motor still doesn’t come on, the battery must be dead. Replace it. |
| Motor & propeller turns when removed from car, but not when attached to car | Propeller is hitting other parts of the car | Move motor & propeller so it isn’t hitting |
| Propeller is hitting the ground | Raise motor and propeller so they don’t hit |
| Propeller and motor come loose when attached to car | Motor is not attached tightly enough | Use more tape or make a pocket in the car body for holding motor |
| Propeller rotates but does not drive car | Car is too heavy | Remove material or use lighter materials |
| Too much friction between wheels and body | Allow wheels to spin freely, as in Lesson 3. See p. 15 |
| Car body obstructs air flow | Remove material from behind propeller |
| Car goes in circles | Axles are not parallel | Reposition axles to make them parallel |
| More friction on one side | Check to see that wheels can turn equally freely on both sides; if not , reduce friction on slow side |
| Car goes backwards | Motor is turning in the wrong direction | Reverse the wires from the motor, or to the battery. See p. 10. |
| Car tips over | Weight is unbalanced | Add weights, such as steel washers; move battery; or redesign body so weight is better distributed |

Lesson 7. Add Lights to your Car

Powering a LED from a coin battery

LED stands for **light-emitting diode**. A diode is an electronic component that can pass current in only one direction – kind of like a one-way valve or “exit only” for electrons, and therefore, electric current. The LED has a long wire and a short wire. It will not light up unless the long wire is touching the “+” side of the battery, and the short wire is touching the “—" side, and the two wires are not touching each other. With an ordinary light bulb, you could reverse the direction, and the bulb would still light up. Because the LED allows current to flow only one way, reversing the wires will not work. A device that can be connected only one way is called **polar**.

The flat side of the coin battery is the (+) terminal. To light a LED, the long wire, or leg, needs to connect with the (+) terminal, and the short leg has to touch the (—) side. A LED will also work from two AA batteries in series but it is much easier to connect them to coin batteries.

Connecting a LED to a switch

It is difficult to connect the LED to the switch with a wire. The LED legs are stiff and do not twist easily with a wire. One way to connect them is to wrap the wire around the LED leg, fold the end of the leg over on the wire, and wrap wire and leg with tape.

Series and parallel circuits

To operate more than one LED from a coin battery, the LEDs have to be in parallel. They will work in parallel, but not in series. Even in parallel, some LED combinations won’t work. Two of the same color will always work together, and red works with yellow, but if you put green in parallel with either red or yellow, the green one won’t light up.

Series and parallel circuits are summarized below (switches are not shown):

|  |  |  |
| --- | --- | --- |
|  | Parallel connection: YES | Series Connection: NO |
| Two LEDs | NOTE: LED’s must be same color, or combination of yellow & red; green will not work with either yellow or red. |  |

Here is how to connect two LEDs in series: 1. connect the +side of the battery to the long leg of the first LED; 2. Connect the short leg of the first LED to the long leg of the second LED; and 3. The short leg of the second LED to the negative side of the battery. Remember, each LED requires about 3 volts, so two LEDs in series require 6 volts.

Design requirements

An important part of engineering design is to develop the criteria that the design is to meet. For the headlight circuit most students will want to turn both headlights on and off with one switch, so both lights have to be in the same circuit. They will want the headlights to stay on, so they won’t use a push-button switch. One way to connect a circuit with LEDs in parallel is:1. Connect the + side of the battery to the switch; 2. Connect the switch to the long leg of the first LED; 3. Connect the short leg of the first LED to the negative side of the battery. These three steps result in a circuit with the first LED. The second LED may be added to the circuit by connecting the long leg of the second LED to the long leg of the first LED and the short leg of the second LED to the short leg of the first LED. The length of the wires connecting the two LEDs determines how far apart the lights may be placed.

Motor circuits

A motor requires an AA battery – if you use a coin battery to run a motor, it will go dead very quickly.

Adding switches

Each circuit should have its own switch. A simple switch cannot be shared between two separate circuits, each with its own battery. Thus the motor circuit has its own battery (a 1.5 v. AA battery) and switch. Likewise the headlight circuit has its own battery (a 3 v. coin battery) and switch.

Extension 1: Make and Troubleshoot a Direct-drive Car

How does a direct-drive car work? Newton's third law of motion says for every action there is an equal and opposite reaction. For the direct-drive car: the action is the spinning drive-wheel pushing the surface on which it is resting in the direction of motion of the drive-wheel at the point of contact. If the surface is easily moved, as a small piece of paper, the paper is moved. If the surface is more massive than the motor and drive wheel, and whatever they are attached to, then they are moved relative to the surface

Making the direct-drive car. First, be sure to review the on-line materials found here: <http://citytechnology.org/energy-system/5-make-direct-drive-or-friction-drive-car>. The direct-drive car can be made in different ways. The motor with attached drive-wheel may be mounted on the free-rolling car from Lesson 3 along with a battery and switch. If these are mounted on top of the cardboard car body, the drive-wheel usually will not reach the ground below. This problem is solved by mounting the motor on the underside of the cardboard. This will work, but the wheels on one side of the car are lifted off the ground. Some students make a hole in the cardboard so the motor may be mounted in the hole at the right level for the drive-wheel to touch the ground. A problem with this solution is that usually there is not enough friction between the drive-wheel and ground, so the drive-wheel slips. When the drive wheel is lowered so more of the weight of the car rests in the drive-wheel, other wheels are lifted off the ground, as seen in this video: http://citytechnology.org/node/1770. The simplest solution is to make a 3-wheeled car where the drive wheel is one of the three wheels. These videos show ways to do this: <http://citytechnology.org/node/1767> and http://citytechnology.org/node/1768.

Troubleshooting the direct-drive car

The table below shows how to address a variety of issues that can come up in making direct-drive cars. Do not share any of these ideas directly with students. Provide just enough information to prevent frustration. The best way to do this is to ask questions, such as, “What should be touching the ground?” Each issue may have more than one possible cause, so multiple causes are listed for some of the issues, as well as a fix for each one.

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Motor won’t turn | Connections are bad – metal surfaces aren’t touching | Review how to make connections – see “Connecting to an AA battery” under Troubleshooting, Lesson 3 |
| Switch not working (test by putting a wire across the switch) | Review requirements for a switch & types of switches, Troubleshooting, Lesson 2. |
| Battery is dead (test for this by changing to another battery) | Test battery by holding motor wires directly against terminals. If motor still doesn’t come on, battery is dead. Replace it. |
| Motor is bad (test by changing to another motor) | Use another motor |
| Motor spins, but doesn’t turn wheel | Wheel is not attached tightly to motor | Push bushing into wheel, and push motor shaft into bushing, for tight fit |
| Wheel spins when off the ground, but doesn’t drive car when on the ground | Wheels are too high | Wheels must be resting on the ground. Make axle and/or motor ride lower. |
| Too much friction in the wheels that are not attached to the motor | Make sure wheels can spin on axle, or axle can spin on body; see Troubleshooting, Lesson 4. |
| Wheel and motor tip when car is on the ground | Attach motor more firmly to car body |
| Wheels come off | Wheels free to slide on axles | Use a little clay, tape or rubber bands at ends of axles to stop wheels from leaving |
| Car goes in circles | Axles are not parallel | Reposition axles to make them parallel |
| More friction on one side | Check to see that wheels can turn equally freely on both sides; if not , reduce friction on slow side |
| Car goes backwards | Motor is turning in the wrong direction | Reverse the wires from the motor, or to the battery (see Lesson 1, step 3) |
| Car tips over | Weight is unbalanced | Add weights, such as steel washers; move battery; or redesign body so weight is better distributed |

Extension 2: Make and Troubleshoot a Friction-drive Car

Look first at the on-line materials found here: <http://citytechnology.org/energy-system/5-make-direct-drive-or-friction-drive-car>. The friction-drive car is constructed directly on the simple car made in Lesson 3. This video shows how you can do this: <http://citytechnology.org/node/1815>. There are two areas where students often find issues to solve. Both involve placing the drive-wheel and motor in the proper position so the drive-wheel transmits energy to one of the four wheels of the car. First the motor is firmly attached so that the drive-wheel is aligned with and touching a car wheel. The friction between drive-wheel and car wheel must be great enough to overcome the friction between other moving parts of the car. This means they need to press firmly together. If the motor moves or the axel shifts, the drive-wheel and car wheel will not remain in firm contact. Friction between drive-wheel and car wheel can be increased by adding a “tire”, a rubber band that fits snuggly on either car wheel or drive-wheel. The other issue is maintaining alignment between drive-wheel and car wheel. The car wheel often moves slightly from side to side, throwing it out of alignment with the drive-wheel. Students will need to find ways to minimize this movement.

The table below shows how to address a variety of issues that can come up in making direct-drive cars. Do not share any of these ideas directly with students. Provide just enough information to prevent frustration. The best way to do this is to ask questions, such as, “What should be touching the ground?” Each issue may have more than one possible cause, so multiple causes are listed for some of the issues, as well as a fix for each one.

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Motor won’t turn | Connections are bad – metal surfaces aren’t touching | Review how to make connections – see “Connecting to an AA battery” under Troubleshooting, Lesson 3 |
| Switch not working (test by putting a wire across the switch) | Review requirements for a switch & types of switches, Troubleshooting, Lesson 2. |
| Battery is dead (test for this by changing to another battery) | Test battery by holding motor wires directly against terminals. If motor still doesn’t come on, battery is dead. Replace it. |
| Motor is bad (test by changing to another motor) | Use another motor |
| Motor spins, but doesn’t turn drive-wheel | Drive-wheel is not attached firmly to motor shaft. | Fix drive-wheel firmly on motor shaft. If drive-wheel has a hole larger than the shaft, use a bushing on the shaft to increase the diameter of the shaft to fit the drive-wheel. |
| Wheel spins when off the ground, but doesn’t drive car when on the ground | Too much friction in the car wheels. | Make sure wheels can spin on axle, or axle can spin on body; see Troubleshooting in on-line lesson. |
| Not enough friction between the drive-wheel and the car wheel. | Add a rubber band “tire” to the car wheel, or the drive-wheel. |
| Wheels come off | Wheels free to slide on axles | Use a little tape or rubber bands at ends of axles to stop wheels from leaving |
| Car goes in circles | Axles are not parallel | Reposition axles to make them parallel |
| More friction on one side | Check to see that wheels can turn equally freely on both sides; if not , reduce friction on slow side |
| Car goes backwards | Motor is turning in the wrong direction | Reverse the wires from the motor, or to the battery (see Lesson 1, step 3) |
| Car tips over | Weight is unbalanced | Add weights, such as steel washers; move battery; or redesign body so weight is better distributed |

Extension 3: Make and Troubleshoot a Belt-drive Car

The belt - drive car is harder to make than a friction - drive, direct - drive or propeller - drive car. However once it is working, it is typically the most powerful of the four designs, though not nearly as fast as the direct-drive car.

The figure below shows a basic design.



In this basic design, the spool is both a pulley and a wheel. The cardboard body has a notch to fit the pulley, which is mounted on an axle that allows it to turn. The two black wheels at the bottom of the diagram have to be able to rotate also.

A more complex design is to attach two wheels to the axle that holds the spool. In this design, the two additional wheels have to make the car go, so they have to have larger diameters than the pulley, and the pulley, axle and both wheels have to rotate together. This design also requires a way to hold the axle to the body while allowing it to rotate – a **bearing** – which can be made using two pieces of a straw. Construction is more complex too: the axle, pulley and straw pieces and rubber band have to be assembled first, before attaching the straws to the body.

The tables below show how to address a variety of issues that can come up in making belt-drive cars. Do not share any of these ideas directly with students. Provide just enough information to prevent frustration. The best way to do this is to ask questions, such as, “Are you sure all the connections are tight?" Each issue may have more than one possible cause, so multiple causes are listed for some of the issues, as well as a fix for each one.

**Table 1: Issues Related to Circuits and the Car Body**

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Motor won’t turn | Connections are bad – metal surfaces aren’t touching | Review how to make connections – see “Connecting to an AA battery” under Troubleshooting, Lesson 3 |
| Switch not working (test by putting a wire across the switch) | Review requirements for a switch & types of switches, Troubleshooting, Lesson 2. |
| Battery is dead (test for this by changing to another battery) | Test battery by holding motor wires directly against terminals. If motor still doesn’t come on, battery is dead. Replace it. |
| Motor is bad (test by changing to another motor) | Use another motor |
| Wheels come off | Wheels free to slide on axles | Use tape or rubber bands at ends of axles to stop wheels from leaving |
| Car goes in circles | Axles are not parallel | Reposition axles to make them parallel |
| More friction on one side | Check to see that wheels can turn equally freely on both sides; if not , reduce friction on slow side |
| Car goes backwards | Motor is turning in the wrong direction | Reverse the wires from the motor, or to the battery (see Lesson 1, step 3) |
| Car tips over | Weight is unbalanced | Add weights, such as steel washers; move battery; or redesign body so weight is better distributed |

**Table 2: Issues Related to the Belt-Drive Transmission**

|  |  |  |
| --- | --- | --- |
| **Issue** | **Possible Causes** | **Fixes** |
| Rubber band slips off | Motor not secure enough | Attach motor more tightly, using tape or a pocket in the body |
| Rubber band too loose | Move motor further back or use shorter rubber band |
| Pulleys not aligned | Reposition motor or spool |
| Bushing rim is not high enough | Add tape to build up the end of bushing. The diagrams below show two pieces of tape, one on the inside and one on the outside of the bushing rim. Stick these together to form a bigger rim, trim excess. |
| Motor turns when rubber band is off, but not when rubber band is in place | Rubber band too tight | Move motor towards pulley, or pulley towards motor; or use longer rubber band |
| Rubber band rubs against body | Cut larger notch in body or raise motor |
| Spool can’t rotate | Cut wider notch or use smaller axle |
| Rubber band rotates spool, but spool won’t drive car | Spool slips on the ground; there are no other wheels | Run car on rougher surface, add rubber band “tires” to edges of spool, or use more complex design with separate wheels |
| Spool is not touching the ground, because wires or battery are dragging below bottom of spool | Tape battery and wires securely to body; move battery if necessary |

Materials for Propeller - Drive Cars

|  |  |  |
| --- | --- | --- |
| **Item** | **Detail** | **Quantity** |
| AA Batteries |  | 70 |
| Motors w/ 2 mm shafts |  | 35 |
| CR 2032 Coin batteries |  | 70 |
| LED, 10 mm. | Green, | 35 |
| LED, 10 mm. | Red | 35 |
| LED, 10 mm. | Yellow | 70 |
| Wire strippers |  | 6 |
| Wheels w/ 3 mm. holes | Black (Pitsco) | 150 |
| Wooden barbecue skewers | 6 ″ & 8 ″ 100 of each | 200 |
| Straws | Box of 100, ¼ in. diam. | 1 |
| Cardstock | 250 sheets, assorted colors | 1 |
| Cardboard sheets | 8 ½ ″ x 11 ″ | 6 |
| Cardboard rectangles | 4 ¼ ″ x 5 ½ ″ (¼ sheet) | 70 |
| Cardboard strips | 11″ x 1″ | 100 |
| Double sided foam tape | roll | 2 |
| Masking tape | Roll, 1 in. x 60 ft. | 5 |
| Rubber bands | ¼ lb. bag, #64 3.5 x 0.25 in | 1 |
| ¼ lb. bag, #30, 2 x 0.125 in. | 1 |
| Mini-binder clips | Box of 12 | 6 |
| Paper clips | Box of 100, 1 ea., small & large | 2 |
| Paper fasteners | Box of 100, 1.5 in. brass plated | 2 |
| Box of 100, 1 in. brass plated | 1 |
| Insulated wire | 25 ft. roll AWG #24 | 6 |
| Propellers | Plastic with 2 mm hole | 35 |
| Small candy boxes | 2-1/2" X 2-1/2" x 1" | 40 |
| Steel washers | ½ ″, box of 50 | 2 |
| Craft materials | pom-poms, foam stickers, , felt, pipe cleaners, Google eyes, cotton balls, craft sticks, cocktail umbrellas, , colored tissue paper & cellophane |  |

Additional Materials for Direct-, Friction-, and Belt-drive Cars

|  |  |  |
| --- | --- | --- |
| Each extension lesson requires motors, wheels, skewers, batteries, cardboard, materials for battery holders and switches, as above | | |
| **Additional Items** | **Detail** | **Quantity** |
| Drive wheels | 1.5" wheel with 2mm hole | 70: Extension lessons 1 & 2 |
| Rubber bands | ¼ lb. bag, #64 3.5 x 0.25 in | 1: Extension lesson 3 |
| Plastic Spools |  | 35: Extension lesson 3 |

**Lesson 1: Turn a Motor On**

## Essential Question

What can cause a motor to run?

## Task

Complete a circuit including a battery and motor, then reverse the motor direction. Make a battery holder.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations, 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 8. Obtaining, evaluating, & communicating information  
**Cross-cutting Concepts:** 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function

**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* An electric circuit requires a battery (or other source), a load and a path that connects each side of the load to a different side of the battery.
* A motor converts electrical energy to mechanical or kinetic energy (energy of motion).
* To reverse the direction of a motor, reverse the way the wires are attached to the battery, for example, attach the red wire to the “—” side of the battery and black wire to “+” terminal instead of *vice versa*.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Turn on a motor from an AA battery and reverse it | Does not turn on motor | Turns motor on but can't reverse it | Turns motor on, reverses it, and explains how to do it | Identifies polarity of motor wiring (e.g., red wire to + terminal) and direction of motion (e.g., CCW) and records which polarity results in which direction |
| B. Recognize meaning and need for a complete circuit | No writing or drawing | Writing and drawing do not reflect complete circuit | Complete circuit is evident in either circuit drawing or written description | Complete circuit is evident in circuit drawing, diagram, and written description |
| C. Create a battery holder and use it to attach battery to motor | No battery holder | Battery holder does not make reliable connection | Makes a reliable battery holder and uses it to connect to motor | Assists other students with their battery holders |

**Advance Preparation**

* Review the web site at http://www.citytechnology.org/content/turn-motor-0.
* Set up Penguin Race Toy. See the video at the web site or <http://vimeo.com/30576656>.
* Make a sample battery holder. See video at the web site or [http://vimeo.com/21399301](http://vimeo.com/30576656).
* Photocopy worksheets and rubrics.
* Chart paper with the headings "Pictures for a Drawing" and "Symbols for a Diagram"
* Prepare Science Notebooks.

**Materials**

* AA battery and motor – one of each per student
* For making a battery holder: 2” x 3” cardboard, two paper fasteners, tape and a rubber band
* Assembled Penguin Race™ toy – one per class

**Procedure**

1. The Penguin Race™ Toy (Whole class, 15-min.): Lead a brief review of electric circuits. It is likely that students have already had experience with “Batteries and Bulbs” or an equivalent unit. Use chart paper to review what is needed to light a bulb from a battery. Use the Penguin Race Toy to illustrate the concepts (see Troubleshooting for a full discussion):

* the escalator gives the penguins energy;
* they lose this energy as they travel down the slide;
* they need the escalator to get energy again, so they can go back up.

Ask students to think about how the Penguin Race Toy is similar to and different from an electric circuit:

* *In a circuit, what is traveling around?*
* *In the toy, what is traveling around?*
* *Why does the racetrack need to be attached to both the top and bottom of the escalator?*
* *Why does the light bulb need to be attached to both sides of the battery?*

Introduce the concept of a **model**: a simplified version of something that reveals important features of the real thing, without being exactly like the real thing. For example, a doll house is a model of a real house, showing rooms and furniture, but not as big as a real house.

Develop the idea that the Penguin Race toy is a model of an electric circuit.

* *In a circuit,* **current** *measures the rate at which electrons are flowing around. In the toy model, what plays the role of the current? What would I have to do to increase or decrease the current?*
* *In a circuit,* **voltage** *measures how much energy each electron has, and therefore how much it can do. You can increase the voltage by adding batteries. In the toy model, what plays the role of the battery? What would you have to do to increase or decrease the voltage?*

1. What is a motor? (Whole class, 5-min.):Ask students:

* *Where have you seen a motor?*

Students are likely to identify motors in cars, but explain that here we are talking about an **electrical motor**. Except for starter motors, most car motors get their energy from gasoline, but an electrical motor need electricity to work. Develop a brainstorming list of electrical motors that students have seen or know about. Here are some common places you can find electric motors:

* Electric fan
* Refrigerator
* Washing machine
* Dryer
* Vacuum cleaner
* Electric pencil sharpener

Then ask:

* *What does a motor do?*

Develop the idea that a motor uses electrical energy to make something rotate. It converts electrical energy to **kinetic energy**, which means “energy of motion.”

1. Turn the motor on (Individual – 10 min.): Students may have studied electricity using batteries, bulbs and wires, but are probably not familiar with motors. Explain that we will be using a battery to operate a motor rather than a bulb. Ask:

* *How will you be able to tell when the motor is running?*

Provide time for students to experiment.

**Important safety note:** Like other batteries, these cannot give you a shock. However, other forms of electricity are extremely dangerous. Under no circumstances should any student attach anything to a wall outlet or to an electrical appliance that is plugged in.

Introduce the worksheet. There is a place to make a drawing of how students made the motor go and a place to describe how they made it go. Under the place for the drawing is a place for a diagram of how they connected the battery and motor. Engineers have a special way to draw circuits: engineers make diagrams that use symbols. On the chart paper draw a battery, a motor and a wire under the "Drawing" column. Direct students to the top of the worksheet:

* *What symbol should I draw next to the battery? To the motor? To the wire?*
* *What does it mean to call this, cell symbol, a symbol?*

Have students complete the top part of the worksheet.

* *Draw and describe how you made the motor go, then see if you can figure out how to make a diagram, using our symbols, that shows the same thing as your drawing.*

After a few minutes, select two students to make their drawings and diagrams on chart paper (or show them on the Elmo). Discuss the drawings and diagrams the students made, then discuss the good points of both diagrams and drawings.

1. Make the motor turn the opposite way (Individual – 15 min.): Review the directions in which something can rotate: **clockwise** (CW) or **counterclockwise (CCW).** Provide students with tape. Each student should attach a little piece of tape to his or her motor, and observe the direction of rotation:

* *Which way does it go, when viewed from the shaft end: clockwise or counterclockwise?*
* *Which way does it go, when viewed from the opposite end: clockwise or counterclockwise?*
* *What would you have to do to make it go in the reverse direction from each view?*

An alternate way to find the direction of a motor is to attach a propeller, and see which way the air flows. Provide time for students to experiment and record their findings on the Worksheet.

Science Notebook or Worksheet:

* Describe and draw how you made the motor work.
* How is the battery different from a light bulb? How is it similar
* Describe and draw how you made the motor go in the opposite direction.
* What forms of energy are in your circuit?

**Suggested breakpoint between periods**

1. Batteries, loads and energy transformation (Whole class – 5 min.): Introduce the term **load** for anything that electricity can run. The **input** to a load is electrical energy. The **output** from a load is energy in some other form.

* *What form of energy goes into a motor? What form of energy comes out?*
* *What form of energy goes into a light bulb? What form of energy comes out?*

1. Battery holders (Individual – 20 min.): Battery holders allow students to make good connections of wires to batteries. Demonstrate the way to make a simple battery holder. See p. 11 or the video at the web site or at [http://vimeo.com/21399301](http://vimeo.com/30576656).
2. Insulators and conductors (Small Group – 15 min.): Students may have discovered that when the coated part of the wire (rather than the metal center) is touched to the battery, the motor does not work. The metal wire is a conductor. It allows electricity to pass. The coated part of the wire is an insulator. It prevents the flow of electricity. Ask students to

* *Connect the end of one motor wire to the battery.*
* *Place various objects between the end of the second motor wire and the other end of the battery.*
  + *Which objects allow the motor to run? These are conductors.*
  + *Which objects don’t allow the motor to run? These are insulators.*

Students make a list of insulators and a list of conductors in their Science Notebooks.

Science Notebook:

* Make the heading **Conductors**. Under **Conductors** list all the conductors of electricity you found.
* Make the heading **Insulators**. Under **Insulators** list what you found that doesn't conduct electricity.

1. Switches (Whole class, 5-min.): Gather students for a class meeting. Ask students:

* *In the circuits you have made so far, what did you have to do to turn them ON or OFF?*
* *When you turn a TV, light or hair dryer ON or OFF, what do you do?*

This discussion should pave the way for the Switch Hunt (see below).

**Word Bank:** Electric circuit, battery, source, electrons, model, current, voltage, complete circuit, electric motor, electrical energy, chemical energy, kinetic energy, direction of motion, rotation, clockwise, counterclockwise, load, input, output, conductor, insulator, lead.

**Homework**

A Switch Hunt. Provide the Worksheet, Part 2, for students to list switches they can find at home or elsewhere. For each one, they should list where it is located, what it controls, and what you have to do to operate it. For example, a light switch is located on the wall, it controls whether electrical energy will flow to a light fixture, and you operate it by pushing it up (on) or pulling it down (off). Other ways you might operate a switch could be by turning a knob, sliding something, or pushing a button down and holding it.

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

Lesson 1, Part 1: **Motors**

In the drawing, make the battery, wires and motor easy to understand.

In the diagram use symbols: a wire is a straight line, like this: ,

a motor is a circle with a M in it, and two wires sticking out, like this: http://www.cdn.sciencebuddies.org/Files/4665/6/light-bristlebot-motor-symbol_IMG.jpg, and

a single battery is shown like this: cell symbol where the long vertical line is always "+" and the short vertical line is always "-".

How I made the motor turn on (draw, diagram and write)

|  |  |
| --- | --- |
| **Drawing**  **Diagram** | **Description**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

How I made the motor turn in the opposite direction (draw, diagram and write):

|  |  |
| --- | --- |
| **Drawing**  **Diagram** | **Description**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

What forms of energy are in your circuit?

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

Lesson 1, Part 2: **Switch Hunt**

List the switches you found in the classroom or remember from home.

|  |  |  |
| --- | --- | --- |
| Where I found it | What it controls | How to operate it (push, pull, turn, slide) |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

When do you use a switch?

What does a switch do?

Why does a circuit need a switch?

**Lesson 2: Make a Switch**

## Essential Question

What is an easy way to control a motor, to turn it off and on?

## Task: Make a switch, then complete a circuit including a battery a motor and the switch.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations, 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 8. Obtaining, evaluating, & communicating information  
**Cross-cutting Concepts:** 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function

**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* A switch is a reliable way to control a circuit.
* A switch can be made from common materials. It requires two metal contacts to connect it in a circuit. The circuit is open when the switch is off and closed when the switch is on.
* Switches can be operated by sliding, turning, pushing, pulling, or holding something down temporarily.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Identify and record examples of switches in the environment | No examples found | One or two examples, but no explanation of how it works or what it controls | Multiple examples, with explanations of how each one operates and what it controls | (3) + recognition that there are also switches that are hidden |
| B. Describe the need for a switch in a circuit | No description | Description is not clear | Explains that a switch provides a reliable way to turn a circuit on or off, and keeps the battery from dying | (3) + aware that switches are examples of control devices, which include valves, faucets, etc. |
| C. Make a switch and use it to control a circuit | Cannot make a switch | Makes a simple pushbutton switch | Adds switch to a circuit | Makes more than one type of switch, and adds each one to a circuit |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://www.citytechnology.org/content/make-switch-0
* Make four sample switches: a) rotary, b) slide, c) toggle & d) pushbutton. For directions, see Teacher Notes p. 12 or [www.citytechnology.org/sample-switches](http://www.citytechnology.org/sample-switches)
* Photocopy worksheets and rubrics
* Post a sheet of chart paper entitled Switch Hunt, with the headings:  
  “Where it was found,” “What it controls” & “How to operate it.”
* Post a sheet of chart paper labeled Troubleshooting, with the headings:  
  “Issue,” “Cause” & “Fix.”
* Post a sheet of chart paper with a drawing of a circuit, battery and motor, to discuss switch location. See the video at http://citytechnology.org/node/1743.

## **Materials**

* Motor, AA battery and battery holder for each student (see Lesson 1).
* Cardstock, paper clips, paper fasteners, aluminum foil, scissors, small binder clips, tape, wire
* Sample homemade switches: rotary, slide, toggle & pushbutton

**Procedure**

1. Switch hunt (Whole class – 10 min.): Gather students for a class meeting. Review the results of the Switch Hunt students have done for homework. Students will likely have identified switches that are operated in different ways. Discuss the most common types:

* *To operate a* ***rotary*** *switch, you have to turn something, usually a knob. Switches with multiple ON positions are often of this type. For example, the speed control switch on a fan is usually a rotary switch.*
* *To use a* ***toggle*** *switch, you push a lever up or pull it down, and after you move it, it stays there. Most wall light switches are toggle switches.*
* *A* ***pushbutton*** *switch is one that you have to hold down to keep it ON. A computer mouse, keyboard and cell phone all use pushbutton switches.*
* *A* ***slide*** *switch is operated by pushing a tab back and forth. The ON/OFF switch on the Penguin Race Toy is an example of a slide switch.*

Ask students:

* *What is a switch and what does it do?*
* *What could go wrong if a circuit didn’t have a switch?*
* *What kinds of switches have you found? What other examples can you think of, and what is the type of each one?*

1. Designing a switch: (Whole class --10 min.): Explain that we’ll next be making our own switches. Ask:

* *What kind of parts do you think a switch needs to have? Why do you think so?*

Then engage students in thinking what they could use to make a switch:

* *What kinds of stuff do we have here that you could use to make your own switch? How would you make it?*
* *Demonstrate the four switches you have made. With each one ask:*
  + *How does this work?*
  + *Where would you put this in a circuit with a motor and battery holder? (See the video at http://citytechnology.org/node/1743.)*
  + *Will you need extra wires? Where?*

1. Make a switch (Individual -- 25 min.) Provide materials and time for students to make and test their own switches. Each student should select the kind of switch they would like to make: pushbutton, rotary, slide or toggle. Make your sample homemade switches available for students to examine.

**It may be necessary to continue this activity in the next period**

1. Discussion of switches (Whole class 15 min) Students share and compare the switches they have made. After each student has presented a switch, ask the class:

* *What do you have to do to operate this switch?*
* *What type of switch is it (pushbutton, rotary, slide or toggle)? How can you tell?*

Science Notebook: Make a drawing showing how you could put your switch in a circuit, so it could turn the circuit ON and OFF.

* Add your switch to a circuit (Small groups – 20 min.): In order for a switch to work, it has to be in one position for the motor to be ON, and in another position for the motor to be OFF. Using chart paper with a drawing of a circuit, battery and motor, discuss switch location. Below the drawing, make a diagram of the same circuit and discuss where the symbol for the switch should go. See the video at http://citytechnology.org/node/1743.

1. The next challenge is:

* *Put your switch inside a circuit so it controls the motor.*

Review the Worksheet, pointing out the symbol they can use for the switch. At the bottom of the Worksheet students record how they tested their switches.

1. Troubleshooting chart (whole class – 10 min.) Create a chart with the headings “Issue,” “Cause” and “Fix.” Engage the whole class in filling in issues they had, what caused them and how to fix them.

**Word Bank**

switch, push-button switch, rotary switch, slide switch, toggle switch, pull-chain switch, control, contact, open circuit, closed circuit.

**Extension**

Make one or more of the other three types of switches, and add it to a circuit.

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

## Lesson 2: **Make a Switch**

How I made my switch (draw and write):

|  |  |
| --- | --- |
| **Drawing** | **Description**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

How I added my switch to a circuit (draw and write):

The symbol for a switch is

Use these symbols in the diagram (show symbols for wire, battery, motor, switch)

|  |  |
| --- | --- |
| **Drawing**  **Diagram** | **Description**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

How I could tell if my switch was working : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

**Lesson 3: Let’s Roll!**

## Essential Question: How can you make a rolling base for an electric car?

## Task: Make a car platform that rolls easily and straight.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* Something that can roll will move more easily than something that can’t.
* Friction prevents something from moving easily. You have to reduce friction to allow one part to turn while another does not.
* In order to go straight, the axles of a vehicle have to be parallel to each other, and the wheels have equal amounts of friction.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Make a car that rolls | No car | Car does not roll. | Car rolls down a ramp. | Makes car roll better by identifying friction and reducing it. |
| B. Troubleshoot car to make it go straight and go faster | Does not improve car's performance. | Fixes problem but can’t explain how. | Explains fixing a car by making axles parallel and/or reducing friction. | Assists other students in getting their cars to go straight. |
| C. Write and draw to communicate how to construct and fix a car | No writing or drawing. | Writes and / or draws how to make a car and/or fix it, but not clearly. | Makes an instruction manual of at least three steps. | Makes a clear instruction manual and troubleshooting guide. |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://www.citytechnology.org/content/lets-roll-0
* Photocopy worksheets and rubrics
* Post a sheet of chart paper labeled Troubleshooting, with the headings:  
  “Issue,” “Cause” & “Fix.”

## **Materials**

* Wheels (black), four per student
* Skewers, two per student
* Straw, one per student
* Cardboard rectangles, 4 ¼ ″ x 5 ½ ″, one per student, for car
* Cardboard sheet for making a class test slope.
* Tape, scissors, paper fasteners, paper clips, bulldog clips
* Steel washers (for adding weight)

**Procedure**

1. Car talk: (Whole class – 10 min.): Introduce the issue of making a car that will roll easily. In the next lesson, students will be making electric cars, but to do so they will first have to create simpler cars that can roll when pushed or released on a ramp. Ask students:

* *What parts do you think you will need to make a car?*

Introduce the parts available for making cars.

* *How will you put these parts together?*
* *Which parts of your car will be turning and which parts will not be?*

After discussing these issues briefly, provide the Worksheet, Part 1, for students to record their ideas.

1. Make a car: (Individual and small group – 25 min.): Provide materials for making cars, and a cardboard ramp, at least 2' long. After making a first car, tell students to test their cars by gently pushing to see if the car will roll on the desk. Individually or in groups ask:

* *Does it roll easily?*
* *Observe carefully. Do all the wheels turn?*

Next, students test their cars on the class slope. Again tell the students:

* *Observe carefully. How far does the car go?*
* *Does the car go straight?*
* *Do all the wheels turn? Are any wheels rubbing on the car?*

1. Class meeting (Whole class – 10 min.): Discuss the issues that came up. Introduce the words **axle** for the stick that holds the wheels, and **body** for the cardboard platform. On chart paper headed **Troubleshooting**, and columns for *"Issue",* *"Cause"* and *"Fix",* list the issues that students identify. Issues might include "car won't move"," a wheel doesn't turn", "the car doesn't go as far as the cars of others", "the wheels fall off", " the car always turns".

**This may be a good place to break the lesson, continuing the next period.**

1. Class meeting, continued (Whole class – 10 min.): Return to the chart of Issues and discuss possible causes. If something won’t move when you push it or let it go on a ramp, **friction** is preventing it from going. Reducing friction allows the wheels to roll. Ask:

* *For the car to roll, which parts need to be able to turn?*
* *Which parts should not be able to turn?*
* *How can you allow one part to turn, while the other part doesn’t?*

Develop the idea that the wheels need to turn, but the body can’t turn. There are two possibilities:

* The wheels can be fixed to the axles, but then the axles have to be able to turn freely while the body is not turning; or
* The wheels can be loose on the axles, allowing them to rotate freely. This allows the axles to be fixed to the body, but then there needs to be something to stop the wheels from falling off.

Lead a discussion about how to solve the problems of either:

* Allowing the axles to rotate, or
* Keeping the wheels on the axles.

1. Fixing cars (Individual and small group – 10 min): Students troubleshoot their cars, and redesign them if necessary, so they roll easily.
2. Straight or crooked? (Whole class – 10 min.): Once students get their cars to roll, there are still likely to be some issues. A major one will probably be that many cars will not travel in a straight line. (Other issues are addressed in the Troubleshooting section, below). Ask students:

* *If you’re pedaling a bicycle or tricycle, or pulling a wagon, what do you need to do to make it turn?*
* *What has to happen for a wagon or tricycle to go straight?*

Use charts to develop the idea that a vehicle will go straight if the two axles are **parallel**, and will go crooked if the axles are not parallel. See diagrams below:



1. Troubleshooting and writing (Individual 5 min): Provide a short time for students to address the problem of "cars that turn", and then, for homework, use the Worksheet, Part 2: write a **Troubleshooting Guide** and a **Construction Manual**.

**Word Bank**

parallel, axle, body, friction, skewer, bearing, construction manual, troubleshooting guide, issue, fix.

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

## Lesson 3, Part 1: **Designing a Car**

Circle the parts you will use to make a car:

|  |  |
| --- | --- |
| wheels  straw  tape | skewer  cardboard  rubber band |

How will you assemble the parts to make the car (draw and write) ?

|  |  |
| --- | --- |
| Label each part | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

Which parts will be able to turn ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

Which parts will be not able to turn ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

Test your car on a ramp. What issues are there?

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

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

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

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

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

## Lesson 3, Part 2: **How to Make a Car**

1. **Troubleshooting Guide**: How did you solve each issue?

|  |  |
| --- | --- |
| **Issue** | **Fix** |
| \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
| \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

2. **Construction Manual:** draw and explain what to do in each step**:**

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

**Lesson 4: Make a Propeller-drive Car**

## Essential Question: How can you make an electric propeller driven car?

## Task: Design and make a propeller-drive car.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* There are a variety of ways to make a motor drive a car.
* A propeller makes a car go by pushing air in one direction. The car goes in the opposite direction.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Design and make propeller-drive car | Completes top of worksheet only. Begins work on car. | Writes & draws how to assemble car. Most parts labeled. Car does not go. | Car works. Parts labeled and instructions clear on worksheet, no issues identified. | Car goes straight, at least 10', and instructions clear, issues identified.. |
| B. Use energy concepts to explain the car's operation. | No idea about how energy concepts apply | Knows the car needs battery and motor, and these involve energy, but not how they are related | Knows the battery stores chemical energy and motor transforms it to kinetic energy, which makes car go | Recognizes the role of propeller in the car’s movement |
| C. Apply friction concepts to explain issues with the car's operation. | No idea about how friction concepts apply | Awareness of friction, but unable to identify specific examples | Identifies points where friction hinders movement; reduces friction so car can move. | Identifies all major points of friction and reduces it so car goes straight and far. |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://www.citytechnology.org/content/make-belt-drive-or-propeller-drive-car-0
* Photocopy worksheets and rubrics
* Post a sheet of chart paper to sketch possible propeller-car designs.

## **Materials**

* Car made in Lesson 3 and parts to repair them.
* Motor / AA / switch circuit from Lesson 2 and extra wire and switch parts..
* Propeller for each student

**Procedure**

1. Brainstorming electric cars(Whole class – 7 min.): Review what students have done so far:

* They have gotten a motor to run from a battery;
* They have learned how to control a motor using a switch; and
* They have made a car that can run by gravity.

The next challenge is to make a car that runs from a motor. Ask:

* *What are some ways you could use the motor to make the car go?*

Students may suggest using a propeller, attaching a wheel to the motor, using gears, using pulleys, etc. There are four ways we’ll be exploring in this class:

* **Direct-drive**: A wheel is attached directly to the motor. By turning this wheel, the motor makes the car go, like someone pedaling a bicycle or tricycle.
* **Friction-drive**: A wheel attached directly to the motor turns one of the wheels of the car by rubbing directly against it.
* **Propeller-drive**: A propeller is attached directly to the motor. The air blown by the propeller makes the car go, like a propeller-driven plane or boat.
* **Belt-drive**: The motor turns a **pulley**, which is connected to another pulley by a rubber **belt**. The second pulley is what makes the car go. The belt is similar to the chain on a bicycle, and the two pulleys are similar to a bicycle’s sprockets, one on the pedals, and the other on the rear wheel. The differences between pulley-belt and sprocket-chain systems are that a belt is made of smooth rubber, and the pulleys have smooth surfaces.

Explain that we’ll begin by making a propeller-drive car first. There will be time later to make one of the other types.

1. How a propeller-drive works (Whole class – 10 min.): Here is a basic rule: **for anything to move in one direction, there must be a push in the opposite direction**. Give the example:

* *For me to move forward, my foot pushes backward*.
* *Who can give me other examples?*

Release an inflated balloon with instructions to observe the direction it starts moving.

* *What was moving in the opposite direction of the balloon?*

1. Design a propeller-drive car: (Whole class – 8 min.):: Show students a propeller and ask:

* *How could this be mounted on a motor?*
* *How could the motor be mounted on a car?*

As they come up with ideas, suggest they make diagrams on the blackboard or chart paper, for everyone to discuss. Additional questions might be:

* *How could you use the simple car from Lesson 3?*
* *How could you predict the direction the car would go?*
* *What kinds of things would you have to look out for?*

Students will probably suggest attaching the propeller to the motor shaft, and letting the air flow push the car. Since the motor and propeller will be doing all the work, the car could be the simple one from Lesson 3. The Worksheet provides a place to record materials as well as ideas.

1. Make a propeller-drive car and an "issues" list: (Individual and small group – 20 min.) As students are working, ask them to record issues as they come up. The Worksheet provides space for recording them. If time permits, conduct a class meeting to discuss some of the issues for the car.

**Word Bank**

design, propeller-drive.

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

## Lesson 4: **Design and Make a Propeller-drive Car**

List the parts you will need to make a propeller-drive car:

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

How will you assemble the parts to make the car (draw and write) ?

|  |  |
| --- | --- |
| Label each part | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

Test your car. What issues are there?

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

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

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

How will the motor make the car go ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

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

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

**Lesson 5: Troubleshoot and Redesign a Propeller-drive Car**

## Essential Question: How can you find out why a car doesn't work right, and fix it?

## Task: Troubleshoot and redesign a propeller-drive car so it runs well. Write a Troubleshooting Guide.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* Improves the car made in Lesson 4 by troubleshooting and redesign.
* A Troubleshooting Guide will capture what you have learned about making a complex system work.
  + Friction can prevent things from moving, and can be reduced by preventing things from rubbing each other.
  + Electrical connections must be tight for current to flow in a circuit.
  + Mechanical connections must be tight in order to transmit power.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Redesigning a propeller-drive car | Does not try to improve the car | Makes cosmetic improvements which do not affect the car operation, only appearance. | Makes changes in arrangement of parts to reduce friction so the car runs better | Makes changes in the parts of the car so it runs better. |
| B. Writing to communicate how to troubleshoot a propeller-drive car | No issues identified | Reproduces troubleshooting guide developed in class | Adds at least one new issue, one cause and one fix to class list | Adds a variety of issues, causes and fixes to class list |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://www.citytechnology.org/content/make-belt-drive-or-propeller-drive-car-0
* Photocopy worksheets and rubrics
* Post the list of issues from end of Lesson4.

## **Materials**

* Partially completed propeller-drive cars made in Lesson 4
* Materials to repair or rebuild propeller-drive car: extra skewers, wheels, straws, cardboard rectangles, 4 ¼ ″ x 5 ½ ″, and cardboard strips, tape, scissors, paper fasteners, paper clips, bulldog clips, wire, AA batteries, motors
* List of “Issues” from Lesson 4

**Procedure**

1. Review of issues cars(Whole class – 5 min.): Meet with the class briefly to review the issues on the list compiled at the end of Lesson 4. Ask students to share their ideas for solving these issues. Remind them to record their ideas and findings on the worksheet or in their Science Notebooks.
2. Troubleshooting, redesigning and rebuilding cars (Individual and small group – 20 min.): Provide time for students to continue working on their cars. Provide troubleshooting assistance only as absolutely necessary – by this point, students should be able to do their own troubleshooting or ask one another for assistance. Students should make changes in their cars to make them work better. This is redesign.

## Troubleshooting Guide cars(Individual – 20 min.): Based on the problems they have learned to solve, each student writes a **Troubleshooting Guide** for his or her car. The Worksheet provides a format. Extra copies of the worksheet should be available if students need them.

**Word Bank**

plan, troubleshoot, redesign, Troubleshooting Guide

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

## Lesson 5: **Propeller-drive Car Troubleshooting Guide**

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

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

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

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

**Lesson 6: How to Make a Propeller-drive Car**

## Essential Question: Can you describe to another how to make a propeller driven car?

## Task: Make an instruction manual for how to make a propeller-drive car.

## **Standards:**

CCLS – ELA**:**

**Writing**: Text types and purposes; Production and distribution of writing; Research to build and present knowledge  
**Speaking & Listening**: Comprehension and collaboration  
**Language**: Vocabulary acquisition and use

NGSS

**Scientific & Engineering Practices:**  2. Developing and using models, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:** 4. Systems and system models;.  
**Disciplinary Core Ideas:** ETS1: Engineering Design

## **Outcomes**

* An instruction manual will tell someone else how to do what you did.
* Writing and diagrams have to be clear and precise, or they will not be useful.
* Writing and diagramming are design processes. You can analyze the weaknesses in your writing and diagrams, and redesign them to make them work better.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Writing and drawing to communicate how to construct a car | No manual | Some steps are present, but others are omitted or steps are not in proper sequence | At least three steps are presented in proper sequence, described in writing and/or drawing | An accurate manual with at least four steps in proper sequence, described in writing and drawing |
| B. Assessing one another's manuals | No assessment | Assessment is not based on rubrics | Student follows rubrics but misses one or two issues | Student follow rubrics closely in assessing manual |
| C. Revision of instruction manual based on other students’ feedback & class discussion | No revision | Revisions are not based on student feedback or class discussion | Revisions are made based on student feedback and class discussion | An accurate manual with four steps in proper sequence, described in writing and drawing |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://www.citytechnology.org/energy-system/7-how-build-direct-drive-or-friction-drive-car.
* Photocopy worksheets, rubrics, and "Student Feedback on another Student's Manual."

## **Materials**

* Propeller-drive cars made by students
* Materials for making cars for use as spare parts.

## **Procedure**

1. Class meeting (Whole class – 5 min.): Students may already be familiar with How-to Books. An engineering term for a How-to Book is an **Instruction Manual**. Meet with students to discuss what an instruction manual is and how it can be used:

* 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.
* 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 – 15 min.): Distribute the Instruction Manual worksheets. Provide time for each student to write his or her own Instruction Manual.
2. Testing instruction manuals. (Whole class , individual– 15 min.): After students have finished writing, demonstrate how to test an Instruction Manual. Select an instruction that is vague, such as “Put the motor on the car” and deliberately misinterpret it; for example, by placing the motor so the shaft is pointing up. Ask students:

* *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 review them using the form “Student Feedback on another Student's Manual”.

1. Revising instruction manuals. (Individual – 10 min.): Ask students to revise their instruction manuals to provide all the information that is needed. Relate this revision to engineering: writing and diagramming are design processes. You can analyze the weaknesses in your writing and diagrams, and redesign them to make them work better. This could be a homework assignment.

**Word Bank**

feedback, instruction manual

**Student Feedback on another Student's Instruction Manual**

**Who wrote the instruction manual?**

**Your Name:**

Read the instruction manual carefully, then answer these questions

**How many steps are there?**

**Examine each step:** (answer only for the number of steps in the manual)

Step 1

Is there a drawing?

Are the parts labeled?

Is there a description?

If so, does the description give the same information as the drawing?

Step 2

Is there a drawing?

Are the parts labeled?

Is there a description?

If so, does the description give the same information as the drawing?

Should this activity come right after the previous step?

Step 3

Is there a drawing?

Are the parts labeled?

Is there a description?

If so, does the description give the same information as the drawing?

Should this activity come right after the previous step?

Step 4

Is there a drawing?

Are the parts labeled?

Is there a description?

If so, does the description give the same information as the drawing?

Should this activity come right after the previous step?

**Look at all the steps**

What steps are left out?

What can be done to improve this Instruction Manual?

What else would you like to say about this instruction manual?

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

Lesson 6: Instruction Manual for Making a Propeller-Drive Car

Number each step. Use more pages if necessary

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

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**Lesson 7: Add Lights to your Car**

## Essential Question: How can you make a headlight sub-system and incorporate it in a propeller-drive car?

## Task: Add a circuit with LEDs for headlights, a coin battery, and switch to the propeller-drive car.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* A system (such as the car) can have more than one circuit such as a light circuit and a motor circuit.
* Each circuit is a sub-system of the car.
* Designing a sub-system includes setting the criteria, or design requirements, the sub-system is to meet.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Design a subsystem for headlights for the propeller-drive car. | No understanding of a subsystem and no design | Understands that a subsystem can be added, but does not understand a parallel circuit | Designs a light system that includes 2 LEDs in parallel and a battery | Designs a light system of 2 LEDs in parallel, a switch, and a battery |
| B. Make and install the headlight system on the propeller-drive car. | Makes no headlight system | Makes a headlight system, but it doesn't work. | Makes a light system of 2 LEDs in parallel, switch and battery. | Installs a working headlight sub-system on the car. |

## **Advance Preparation**

* Review the on-line lesson and related videos at http://citytechnology.org/content/improve-your-ride-add-horn-lights-0
* Photocopy worksheets and rubrics
* Post a sheet of chart paper to sketch possible circuits for headlight systems.
* Make a headlight circuit with two yellow LEDs, a coin battery, a switch and wires long enough so the circuit can be added to the propeller-drive car.

## **Materials**

* Propeller-drive cars made in Lessons 4 and 5.
* Materials for adding lights: LEDs, coin batteries, bull dog clips, paper fasteners, cardboard strips, foam mounting tape, wire, and tape.

**Procedure**

1. Experimenting with LEDs: (Whole class and individual– 10 min.) Distribute one LED, a coin battery and the worksheet "Lesson 7: LED Circuits" to each student.Review the worksheet and the five short experiments students will do. Tell them to begin by making one LED light with one coin battery. Ask:

* *What connections must you make? Will it light any other way? Which "leg" of the LED is connected to what part of the battery? Draw the battery with LED so the connections are clear.*

1. Making circuits with LEDs: (Whole class and individual– 15 min.) Distribute a second LED (same color as the first), 4 wires, and materials for a switch (cardboard strip 1" x 3" and two brass fasteners). Make extra wire available. Tell the students they will do the second experiment: connect one LED to the coin battery using 2 wires. Draw it

Before going on to the next experiment, ask students

* *What problems did you have connecting wires to the LED?*
* *How did you solve the problems?*

Keep track of the problems and solutions on a large sheet under the headings "Problems" and "Solutions". The major problem is usually making a good connection between the wire and the LED. See "Teacher Notes, pp. 19 & 20 for a discussion of this. Different students may have different solutions. This is a design problem.

1. Third experiment: a circuit with one LED, a coin battery and a switch: (Whole class and individual– 10 min.) Students are to make a switch and add it to the circuit from the second experiment, so the switch makes the LED go on and off. Have a couple of students do a quick share of how they made their circuits. Remind students to draw their circuits, using the symbols for battery and switch if they wish.
2. Fourth experiment, a parallel circuit:. (Whole class and individual– 10 min.) In the fourth experiment students, light two LEDs with one coin battery, no switch, no wires, then draw how they did it. After most students have completed the circuit (it is a simple extension of the first circuit so it won't take long) and drawn it, ask two students to share and describe their drawings. Make sure it is clear that the long leg of each LED touches the "+" side of the battery and the short leg of each LED touches the "-" side of the battery. These bulbs are connected "in parallel". The circuit made up of the battery and two LEDs is a "parallel circuit."

* *A parallel circuit is one kind of circuit. Does anyone know what the other kind of circuit is?*
* *How is a series circuit different than a parallel circuit?*
* *How could we connect two LEDs in series?*

**This is a good point at which to break the lesson**

1. Fifth experiment, a headlight circuit: (Whole class and individual– 25 min.) Using what they have learned from the first four experiments, students make a headlight circuit. This will be a sub-system in the total car. They will make the circuit with 2 LEDs, a coin battery, and a switch that controls both LEDs. They may use as many or as few wires as they wish. Begin the lesson by demonstrating the circuit with two LEDs and a battery. This is one way to light two LEDs, but headlights need to be further apart. Then demonstrate the circuit made in the third experiment: an LED connected by wires to a battery and switch.

* *How can you add a second LED to the circuit containing a battery, switch and one LED?*

First ask students to list the design requirements (or criteria) for a headlight circuit that can be added to the propeller-drive car. Possible design requirements include: two headlights; same color lights(white or yellow); lights able to be placed 3" apart; and both lights controlled by one switch. Ask students to do a quick sketch of how they think they will make the circuit. Then, with assistance from students, make large drawings on chart paper of possible ways to make the headlight circuit. For each possible circuit, ask if it will meet the design requirements. After possible circuits have been proposed and vetted as meeting the design requirements, students begin making their headlight circuits. If you think it would be helpful, show the headlight circuit you made to students having trouble - with the proviso that they explain to you how it works.

1. Add the headlight sub-system to the propeller-drive car. (Whole class and individual– 10 min.) Announce that when the circuits are completed, students may add the headlight sub-systems to their cars.
2. Class meeting to discuss progress on the car: (Whole class– 10 min.) Invite students to discuss, and show, their progress on adding the headlight sub-system, the problems they faced, and how they solved them. Tell students that in the next period there will be time to complete the work on their cars and write an instruction manual.

**Word Bank**

Parallel circuit, series circuit, design requirements or criteria, sub-system.

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

## Lesson 7: LED Circuits

Make circuits and draw them. Use the materials listed in the first column.

|  |  |
| --- | --- |
| Make the circuit | Draw the circuit |
| One LED and  coin battery |  |
| One LED, coin battery and  2 wires |  |
| One LED, coin battery, and a switch plus wires |  |
| Two LEDs and coin battery |  |
| Two LEDs, coin battery, wires and switch |  |

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

## Lesson 7a: Design a Headlight Circuit

What parts will you need for the headlight circuit? The table has been started for you. Now complete it.

|  |  |
| --- | --- |
| Part | How many of each part? |
| LED lights |  |
| Wires |  |
|  |  |
|  |  |
|  |  |
|  |  |

Make a drawing of the headlight circuit. You may use symbols for batteries and switches, however clearly draw the LEDs and the connections made.

|  |
| --- |
|  |

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

## Lesson 7b: Install the Headlight Subsystem

In the spaces below there is a top-view and a side-view of the propeller car with no headlight subsystem. Draw the way you will add the headlight subsystem.

Top view of the Propeller-car: show how you will add the lights.

|  |
| --- |
|  |

Side view of the Propeller-car: show how you will add the lights.

|  |
| --- |
|  |

**Lesson 8: Preparations for the Auto Show**

## Essential Question: How can you present your car and its construction to an audience?

Task: Students complete their cars and prepare for presenting their work to the class. They draw and write an instruction manual for how to make the car.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations, 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 8. Obtaining, evaluating, & communicating information  
**Cross-cutting Concepts:**, 4. Systems and system models

**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* Make final improvements on the propeller-drive car.
* Prepare an instruction for the improved propeller-drive car.
* Design the presentation of the propeller-drive car..

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Objective: | Below (1) | Approaching (2) | Proficient (3) | Advanced (4) |
| A. Write and draw an instruction manual for how to make the car | No instructions or unclear instructions | Some steps are present, but others are omitted or steps are not in proper sequence | Clear instructions for a propeller car and motor circuit | Clear instructions for adding a head light circuit to the propeller car. |
| B. The car is ready for presentation | The car does not run. | The car runs, but there is no switch or it doesn’t work. | The car and switch work. Head lights present but not working. | Car and head lights work. |

**Advance Preparation**

* Make copies of the worksheets for making the propeller-drive car and its circuits

**Materials**

* Partially completed cars from Lesson 7
* Materials for making repairs: AA batteries, LEDs, coin batteries, paper fasteners, paper clips, aluminum foil, wire, rubber bands, cardstock, cardboard, scissors, tape, foam
* Materials for decorating cars such as construction paper, ribbon, pom-poms, paper streamers, yarn, felt, pipe cleaners, beads, buttons, etc. (as available).

**Procedure**

1. Prepare cars for presentation: Students complete their cars, test them, troubleshoot, and redesign as necessary. Then they add decoration if they have time.
2. Instructions for how to make the car: Someone might not know what they would have to do to make a car and its circuits. They need an Instruction Manual, or a “How-to” Manual. Distribute the worksheets for how to make the propeller-drive car and how to make its motor and headlight circuits. This is a composite of the drawings and descriptions students have made throughout the unit. Developing the Instruction Manual can be a homework assignment. It is important preparation for the class presentation.

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

Lesson 8: Instruction Manual for Making a Propeller-drive Car

Number each step. Use more pages if necessary

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

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

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

**Lesson 8: Instruction Manual for the Propeller-drive Car Circuits**

**Draw and write how to make each circuit**

|  |  |
| --- | --- |
| Motor circuit | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

|  |  |
| --- | --- |
| Head light circuit | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

**Lesson 9: The Auto Show**

**Essential Question**

How can others find out about what you did and what you learned from making your electric car?

**Task**

Present your electric car to an audience

**Standards**

CCLS -- ELA

**Speaking & Listening:** Presentation of knowledge and ideas

NGSS

**Scientific & Engineering Practices**: 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:** 4. Systems and system models;.  
**Disciplinary Core Ideas:** ETS1: Engineering Design

**Outcome**

Communicating information and ideas is a major part of developing new knowledge

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Present an electric car to an audience | No presentation | Presentation is unclear or incomplete; can’t say how it works or what troubleshooting was done | Demonstration of a working car including description of how it works and/or troubleshooting that was done | Presentation of how the car works, troubleshooting and how it could be improved |

## **Advance Preparation**

* Prepare space and invite audience for presentations

## **Materials**

* Electric cars and Instruction Manuals completed in Lesson 8

**Procedure**

## Presenting Electric Cars (Whole class – 50 min.) This is the culminating lesson, where students will present their final products to an audience. The display could take one or more of several forms:

* **Formal presentation**: Each student shows his or her electric car to an audience and explains how it works and the troubleshooting that was done.
* **Museum**: Students create a display on tables, where visitors can view the Electric Cars and the Instruction Manuals that go with them.
* **Invention Convention**: Like a Science Fair, visitors come to view the Electric Cars, test them out and talk with the students who made them.

**Extension 1: Make and Troubleshoot a Direct-drive Car**

## Essential Question: How can you make and troubleshoot a direct- drive car ?

## Task: Design, make and improve a direct-drive car so it runs well. Write a Troubleshooting Guide.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* There are a variety of ways to make an electric motor driven car.
* Design a direct-drive car.
* In a direct-drive car a drive-wheel attached to the motor shaft makes direct contact with the floor. As it turns it pushes the car. To reverse the direction of the car, reverse the motor connections to the battery.
* Troubleshoot a direct-drive car.
* Redesign a direct-drive car.
* Write a Troubleshooting Guide
  + Friction can prevent things from moving, and can be reduced by preventing things from rubbing each other.
  + Lack of friction may result in slippage between a drive-wheel and the floor.
  + Electrical connections must be tight for current to flow in a circuit.
  + Mechanical connections must be tight in order to transmit power.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Design and make a direct-drive car | Completes top of worksheet only. Begins work on car. | Writes & draws how to assemble car. Most parts labeled. Car does not go. | Car works. Parts labeled and instructions clear on worksheet, no issues identified. | Car goes straight, at least 10' and instructions are clear and issues identified. |
| B. Use energy concepts to explain the car's operation. | No idea about how energy concepts apply | Knows the car needs battery and motor, and these involve energy, but not how they are related | Knows the battery stores chemical energy and motor transforms it to kinetic energy, which makes car go | Recognizes the role of the drive-wheel in the car’s movement. |
| C. Apply friction concepts to explain issues with the car's operation. | No idea about how friction concepts apply | Awareness of friction, but unable to identify specific examples | Identifies points where friction hinders and helps movement; | Identifies points where friction needs to be increased or decreased and modifies the car so it goes straight and far. |
| D. Redesigning a direct-drive car | Does not try to improve the car | Makes cosmetic improvements which do not affect the car operation, only appearance. | Makes changes in arrangement of parts so the car runs straighter | Makes changes suggested by the analysis of friction so the car runs better. |
| E. Writing how to troubleshoot a direct-drive car | No issues identified | Reproduces troubleshooting guide developed in class | Adds at least one new issue, one cause and one fix to class list | Adds a variety of issues, causes and fixes to class list |

## **Advance Preparation**

* Review the on-line lesson and related videos at <http://citytechnology.org/energy-system/5-make-direct-drive-or-friction-drive-car>
* Photocopy worksheets and rubrics
* Post a sheet of chart paper to sketch possible direct-car designs.

## **Materials**

* Motor, AA battery and battery holder for each student (see Lesson 1), plus the large drive-wheel.
* Cardstock, paper clips, paper fasteners, scissors, small binder clips, tape, wire.
* Skewers, two per student, straw, one per student, wheels (black), four per student
* Cardboard rectangles, 4 ¼ ″ x 5 ½ ″, and 1” x 12” cardboard strips.
* Tape, scissors, paper fasteners, paper clips, bulldog clips, wire stripper

**Procedure**

1. Introduce direct-drive cars (Whole class – 10 min.): Review the propeller-drive car students made, asking them how it worked. Demonstrate a circuit with battery, switch, and motor with a propeller attached. Then remove the propeller and replace it with the large drive-wheel.

* *How could the motor and this drive-wheel be used to make a car go?*

Put the motor and drive-wheel circuit on a desk and turn it on.

* *How could we harness this energy of motion to make a car that goes straight?*

As students come up with ideas, make quick sketches on the blackboard or chart paper, for everyone to discuss. Hold up the 4-wheel base that was used with the propeller-drive car.

* *How could you use this simple car for a direct-drive car?*

If students suggest putting the motor on top of the cardboard, show what happens: the motor doesn’t touch the ground so it doesn’t move the car. If they suggest putting the motor under the car, show that it can work, but it lifts two of the wheels off the ground. If they suggest moving the motor and drive-wheel so the drive-wheel rubs against another wheel, agree that this is possible and they will try this when they make friction-drive cars.

* *Does a car have to have four wheels? Could we use only three?*
* *Instead of using cardboard rectangles for the car, could we use long strips?*

After holding up the 1” x 12” strips ask if they have any other ideas about how to make a direct-drive car. Quickly let them share any ideas they may have, then distribute the worksheet “Extension 1a: Design and Make a Direct-drive Car” for students to record their plans and analysis of issues with the car.

1. Students design, then make a direct-drive car (Individual – 20 min.):

Students decide the materials they will need and how they will assemble them, then begin building their cars. They may use the sub-systems already made (battery holder and switch) and attach the drive-wheel to the motor shaft.

1. Issues list and class meeting(Individual / whole class – 15 min.): As students are working, ask them to record issues (problems they encounter or things that don't work right) as they come up. The Worksheet provides space for recording them. Conduct a class meeting to discuss and record on a class chart the issues students had with their direct-drive cars. You may use a chart similar to worksheet “Extension 1b: Direct-drive Car Troubleshooting Guide”. Ask students what they think was the cause of the issue and how they think they could fix it. Write their responses on the chart. Students may use some of these for their troubleshooting charts

**Suggested breakpoint between periods**

1. Review of issues (Whole class – 5 min.): Meet with the class briefly to review the issues on the list compiled at the end of the previous class. Ask students to share their ideas for solving these issues. Remind them to record their ideas and findings on the worksheet “Extension 1b: Direct-drive Car Troubleshooting Guide” or in their Science Notebooks.
2. Troubleshooting, redesigning and rebuilding cars (Individual and small group – 20 min.): Provide time for students to continue working on their cars. Provide troubleshooting assistance only as absolutely necessary – by this point, students should be able to do their own troubleshooting or ask one another for assistance. Students should make changes in their cars to make them work better. This is redesign.

## Troubleshooting Guide cars(Individual – 20 min.): Based on the problems they have learned to solve, each student writes a **Troubleshooting Guide** for his or her car. The Worksheet provides a format. Extra copies of the worksheet should be available if students need them.

Note: Following completion of the direct-drive cars, students may wish to make further improvements in their cars and have an “Auto Show” similar to what was done in Lessons 8 and 9.

**Word Bank**

direct-drive, drive-wheel

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

## Extension 1a: **Design and Make a Direct-drive Car**

List the parts you will need to make a direct-drive car:

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

How will you assemble the parts to make the car (draw and write) ?

|  |  |
| --- | --- |
| Label each part | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

Test your car. What issues are there?

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

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

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

How will the motor make the car go ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

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

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

## Extension 1b: **Direct-drive Car Troubleshooting Guide**

|  |  |
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| Issue: | |
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**Extension 2: Make and Troubleshoot a Friction-drive Car**

## Essential Question: How can you make and troubleshoot a friction- drive car ?

## Task: Design, make and improve a friction-drive car so it runs well. Write a Troubleshooting Guide.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* There are a variety of ways to make an electric motor driven car.
* Design a friction-drive car.
* In a friction-drive car a drive-wheel attached to the motor shaft makes direct contact with one of the car’s wheels. As the drive-wheel turns, it turns the car wheel it is touching. As the car wheel turns, it moves the car. If the car wheel turns clockwise, the wheel it touches will be turned counterclockwise. To reverse the direction of the car, reverse the motor connections to the battery.
* Troubleshoot a friction-drive car.
* Redesign a friction-drive car.
* Write a Troubleshooting Guide
* To fix a problem, first you have to know what’s causing it.
* A Troubleshooting Guide will capture what you have learned about making a complex system work.
  + Friction can prevent things from moving, and can be reduced by preventing things from rubbing each other.
  + Lack of friction may result in slippage between a drive-wheel and the car wheel it is to turn.
  + Poor alignment between drive-wheel and the driven wheel will limit the power transmitted from one to the other
  + Electrical connections must be tight for current to flow in a circuit.

**Assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Design and make a friction-drive car | Completes top of worksheet only. Begins work on car. | Writes & draws how to assemble car. Most parts labeled. Car does not go. | Car works. Parts labeled and instructions clear on worksheet, no issues identified. | Car goes straight, at least 10' and instructions are clear and issues identified. |
| B. Use energy concepts to explain the car's operation. | No idea about how energy concepts apply | Knows the car needs battery and motor, and these involve energy, but not how they are related | Knows the battery stores chemical energy and motor transforms it to kinetic energy, which makes car go | Recognizes the role of the drive-wheel in the car’s movement. |
| C. Apply friction concepts to explain issues with the car's operation. | No idea about how friction concepts apply | Awareness of friction, but unable to identify specific examples | Identifies points where friction hinders and helps movement; | Identifies points where friction needs to be increased or decreased and modifies the car so it goes straight and far. |
| D. Redesigning a friction-drive car | Does not try to improve the car | Makes cosmetic improvements which do not affect the car operation, only appearance. | Makes changes in arrangement of parts so the car runs straighter | Makes changes suggested by the analysis of friction so the car runs better. |
| E. Writing how to troubleshoot a friction-drive car | No issues identified | Reproduces troubleshooting guide developed in class | Adds at least one new issue, one cause and one fix to class list | Adds a variety of issues, causes and fixes to class list |

## **Advance Preparation**

* Review the on-line lesson and related videos at <http://citytechnology.org/energy-system/5-make-direct-drive-or-friction-drive-car>
* Photocopy worksheets and rubrics
* Post a sheet of chart paper to sketch possible friction-car designs.

## **Materials**

* Motor, AA battery and battery holder for each student (see Lesson 1), plus the large drive-wheel.
* Cardstock, paper clips, paper fasteners, scissors, small binder clips, tape, wire.
* Skewers, two per student, straw, one per student, wheels (black), four per student
* Cardboard rectangles, 4 ¼ ″ x 5 ½ ″.
* Tape, scissors, paper fasteners, paper clips, bulldog clips, wire stripper

**Procedure**

1. Introduce friction-drive cars (Whole class – 10 min.): (For students who have made propeller-drive cars but not direct-drive cars.) Review the propeller-drive car students made, asking them how it worked. Demonstrate a circuit with battery, switch, and motor with a propeller attached. Then remove the propeller and replace it with the large drive-wheel.

* *How could the motor and wheel be used to make a car go?*

Put the motor and drive-wheel circuit on a desk and turn it on.

* *How could we harness this energy of motion to make a car that goes straight?*

As students come up with ideas, make quick sketches on the blackboard or chart paper, for everyone to discuss. Hold up the 4-wheel base that was used with the propeller-drive car.

* *How could you use this simple car for a friction-drive car?*

If students suggest positioning the drive-wheel on the simple car so it pushes on the ground, agree that this is possible and they will try this when they make friction-drive cars. Keep the discussion open to see if anyone suggests moving the motor and drive-wheel so the drive-wheel rubs against another wheel. If no one does, then turn the motor on and hold the drive-wheel against one of the wheels of the simple car.

* *Now what ideas do you have for designing a friction-drive car?*
* *Where will you put the motor?*
* *Does it matter which wheel the drive-wheel rubs against?*

Quickly let them share any ideas they may have, then distribute the worksheet “Extension 2a: Design and Make a Friction-drive Car” for students to record their plans and analysis of issues with the car.

1. Students design, then make a friction-drive car (Individual – 20 min.):

Students decide the materials they will need and how they will assemble them, then begin building their cars. They may use the sub-systems already made (the circuit with a battery holder, motor, and switch, the simple 4-wheel car base) or make new ones.

1. Issues list and class meeting(Individual / whole class – 15 min.): As students are working, ask them to record issues (problems they encounter or things that don't work right) as they come up. The worksheet provides space for recording issues. Conduct a class meeting to discuss and record on a class chart the issues students had with their friction-drive cars. The chart can take the form of worksheet “Extension 2b: Friction-drive Car Troubleshooting Guide”. Ask students what they think was the cause of the issue and how they think they could fix it. Write their responses on the chart. Students may use some of these issues for their troubleshooting charts

**Suggested breakpoint between periods**

1. Review of issues (Whole class – 5 min.): Meet with the class briefly to review the issues on the list compiled at the end of the previous class. Ask students to share their ideas for solving these issues. Remind them to record their ideas and findings on the worksheet “Extension 2b: Friction-drive Car Troubleshooting Guide” or in their Science Notebooks.
2. Troubleshooting, redesigning and rebuilding cars (Individual and/or small group – 20 min.): Provide time for students to continue working on their cars. Provide troubleshooting assistance only as absolutely necessary – by this point, students should be able to do their own troubleshooting or ask one another for assistance. Students should make changes in their cars to make them work better. This is redesign.

## Troubleshooting Guide (Individual – 20 min.): Based on the problems they have learned to solve, each student writes a **Troubleshooting Guide** for his or her car. The Worksheet provides a format. Extra copies of the worksheet should be available if students need them.

Note: Following completion of the friction-drive cars, students may wish to make further improvements in their cars and have an “Auto Show” similar to what was done in Lessons 8 and 9.

**Word Bank**

friction-drive

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

## Extension 2a: **Design and Make a Friction-drive Car**

List the parts you will need to make a friction-drive car:

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

How will you assemble the parts to make the car (draw and write) ?

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| Label each part | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

Test your car. What issues are there?

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

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How will the motor make the car go ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

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## Extension 2b: **Friction-drive Car Troubleshooting Guide**

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**Extension 3: Make and Troubleshoot a Belt-drive Car**

## Essential Question: How can you make and troubleshoot a belt- drive car?

## Task: Design, make and improve a belt-drive car so it runs well. Write a Troubleshooting Guide.

## **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, 2. Developing and using models, 3. Planning and carrying out investigations , 4. Analyzing and interpreting data, 6. Constructing explanations and designing solutions, 7. Engaging in argument from evidence, 8. Obtaining, evaluating, & communicating information

**Cross-cutting Concepts:**. 1. Patterns, 2. Cause and effect: mechanism and prediction, 4. Systems and system models, 5. Energy and matter: flows, cycles and conservation, 6. Structure and function  
**Disciplinary Core Ideas:** PS2: Motion and stability: forces and interactions, PS3: Energy, ETS1: Engineering Design

## **Outcomes**

* Design a belt-drive car.
* In a belt-drive car the motor turns the motor shaft, which transmits motion to a pulley (spool) mounted on the car axle through a flexible belt (rubber band). The turning spool makes the car go in one of two ways:
  + If there are no other wheels on the axle, or if they are smaller than the spool, then the spool rests on the ground and its turning moves the car.
  + If the spool is firmly attached to the axle, the spool rotates the axle as it turns. The rotating axle will then turn the car wheels which are attached to it, causing the car to move.
* To reverse the direction of the car, reverse the motor connections to the battery.
* Troubleshoot a belt-drive car.
* Redesign a belt-drive car.
* Write a Troubleshooting Guide
* To fix a problem, first you have to know what’s causing it.
* A Troubleshooting Guide will capture what you have learned about making a complex system work.
  + Friction can prevent things from moving, and can be reduced by preventing things from rubbing each other.
  + Lack of friction may result in slippage between the motor shaft and rubber band, the rubber band and the spool, the spool and the axle, the axle and the wheels, and between the wheels and the ground: Mechanical connections must be tight in order to transmit power.
  + Electrical connections must be tight for current to flow in a circuit.

**Assessment**

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| --- | --- | --- | --- | --- |
| **Objective:** | **Below (1)** | **Approaching (2)** | **Proficient (3)** | **Advanced (4)** |
| A. Design and make a belt-drive car | Completes top of worksheet only. Begins work on car. | Writes & draws how to assemble car. Most parts labeled. Car does not go. | Car works. Parts labeled and instructions clear on worksheet, no issues identified. | Car goes straight, at least 10' and instructions are clear and issues identified. |
| B. Use energy concepts to explain the car's operation. | No idea about how energy concepts apply | Knows the car needs battery and motor, and these involve energy, but not how they are related | Knows the battery stores chemical energy and motor transforms it to kinetic energy, which makes car go | Recognizes the role of the parts of the belt-drive in turning the car’s wheels. |
| C. Apply friction concepts to explain issues with the car's operation. | No idea about how friction concepts apply | Awareness of friction, but unable to identify specific examples | Identifies points where friction hinders and helps movement; | Identifies points where friction needs to be increased or decreased and modifies the car so it goes straight and far. |
| D. Redesigning a belt-drive car | Does not try to improve the car | Makes cosmetic improvements which do not affect the car operation, only appearance. | Makes changes in arrangement of parts so the car runs straighter | Makes changes suggested by the analysis of friction so the car runs better. |
| E. Writing how to troubleshoot a belt-drive car | No issues identified | Reproduces troubleshooting guide developed in class | Adds at least one new issue, one cause and one fix to class list | Adds a variety of issues, causes and fixes to class list |

## **Advance Preparation**

* View these videos of Belt - Drive cars: http://citytechnology.org/node/1799, http://citytechnology.org/node/1808, and http://citytechnology.org/content/make-belt-drive-or-propeller-drive-car-0
* Chart paper for design suggestions.
* Demonstration materials for Belt - Drives see below.
* Photocopy worksheets.

## **Materials**

* Motor, AA battery and battery holder for each student (see Lesson 1), materials for switches (Lesson 2), and for making a simple car (Lesson 3)
* Rubber bands #64 3.5 x 0.25 in. and spools for each student
* Additional supplies: paper clips, paper fasteners, scissors, binder clips (small and large), tape, wire, wire stripper and cardboard rectangles (5” x 8” in addition to smaller size.)

**Procedure**

1. Design a belt-drive car (Whole class, 10 minutes) Make a motor circuit with battery and switch. Loop a rubber band around the motor shaft, and use a pencil to support a spool. The spool should be able to rotate. Show students how a rubber band can be looped over both the shaft and the spool. If the rubber band is stretched slightly, turning the motor shaft will also turn the spool. Have a student help you show this by turning on the motor while you hold the motor and spool. See diagram below. The two pulleys are the motor shaft and spool, and the rubber band is the belt.



How a motor can drive a pulley (spool) through a belt (rubber band)

Ask:

*With the motor circuit and rubber band turning the spool, how could you use this spool to drive a car?*

A simple way is to make the spool do double duty as a wheel, as seen in this video: <http://citytechnology.org/node/1799>. That way it can drive the car without having a tight connection to an axle and wheels. Another way is to make the axle fit snugly in the spool, and attach the axle to wheels snugly at either end. In this design, shown in this video, <http://citytechnology.org/node/1808>, the spool turns the axle, which will make the wheels turn too.

1. Students design, then make a belt-drive car (Individual – 20 min.): Distribute worksheet “Extension 3a: Design and Make a Belt-drive Car.” Students decide the materials they will need and how they will assemble them, then begin building their cars. They may use the sub-systems already made (battery holder and switch). A piece of cardboard about 5” x 8” works well for the car body
2. Issues list and class meeting(Individual / whole class – 15 min.): As students are working, ask them to record issues (problems they encounter or things that don't work right) as they come up. The Worksheet provides space for recording them. Conduct a class meeting to discuss and record on a class chart the issues students had with their belt-drive cars. You may use a chart similar to worksheet “Extension 3b: Belt-drive Car Troubleshooting Guide”. Ask students what they think was the cause of the issue and how they think they could fix it. Write their responses on the chart. Students may use some of these for their troubleshooting charts

**Suggested breakpoint between periods**

1. Review of issues (Whole class – 5 min.): Meet with the class briefly to review the issues on the list compiled at the end of the previous class. Ask students to share their ideas for solving these issues. Remind them to record their ideas and findings on the worksheet “Extension 3b: Belt-drive Car Troubleshooting Guide” or in their Science Notebooks.
2. Troubleshooting, redesigning and rebuilding cars (Individual and small group – 20 min.): Provide time for students to continue working on their cars. Provide troubleshooting assistance only as absolutely necessary – by this point, students should be able to do their own troubleshooting or ask one another for assistance. Students should make changes in their cars to make them work better. This is redesign.

## Troubleshooting Guide cars(Individual – 20 min.): Based on the problems they have learned to solve, each student writes a **Troubleshooting Guide** for his or her car. The Worksheet provides a format. Extra copies of the worksheet should be available if students need them.

Note: Following completion of the belt-drive cars, students may wish to make further improvements in their cars and have an “Auto Show” similar to what was done in Lessons 8 and 9.

**Word Bank**

belt-drive, pulley

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

## Extension 3a: **Design and Make a Belt-drive Car**

List the parts you will need to make a belt-drive car:

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

How will you assemble the parts to make the car (draw and write) ?

|  |  |
| --- | --- |
| Label each part | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

Test your car. What issues are there?

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

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

How will the motor make the car go ? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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

## Extension 3b: **Belt-drive Car Troubleshooting Guide**

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**Glossary**

**Axle**: stick that connects two wheels

**Battery**: a source of electricity, which operates by converting chemical to electrical energy

**Bearing**: component that allows one part to move freely against another, reducing friction

**Belt-drive**: a car that is powered by using a motor to turn a pulley that connects to the drive wheel by a belt and another pulley

**Body:** major part of a car, which all the other parts are built on

**Chemical energy:** a form of energy that is released bya chemical reaction

**Clockwise:** the direction of motion of a standard clock: left to right on top; right to left on the bottom

**Closed circuit**: a system that guides the flow of electricity, and converts electrical energy into some other form

**Complete circuit**: see **closed circuit**

**Conductor**: a material that supports the flow of electricity; nearly all common conductors are metals

**Construction manual**: a book that tells you how to make something

**Contact**: a conductor that connects part of a switch to the rest of the circuit

**Control**: a device that regulates the flow of energy; examples are faucets, valves, circuit breakers and switches

**Counterclockwise**: the opposite direction from **clockwise**

**Current**: the flow of electrical charges, which carry electrical energy

**Design requirements or criteria**: What you would like a design to do **sub-system.**

**Design**: effort to create something that will solve a problem

**Direct-drive**: a car that is powered by attaching a drive wheel directly to a motor

**Direction of motion**: the path of a moving object

**Drive-wheel:** a wheel that powers a car by pushing against the ground

**Electric circuit**: see **closed circuit**

**Electric motor**: a device that converts electrical energy into kinetic energy of a rotating shaft

**Electrical energy**:

**Electrons:** tiny invisible particles that carry electrical energy

**Fix**: a method of correcting an issue

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

**Friction-drive:** a car that is powered by wheel that forces the drive wheel turn by friction between them

**Input**: energy or information that has to be supplied to a system

**Instruction manual**: a book that tells you how to do something, step-by-step

**Insulator**: a material that blocks the flow of electricity; the opposite of a conductor; examples are wood, plastic, paper and air

**Issue:** a problem in the operation of a device

**Kinetic energy**: the energy carried by a moving object

**Lead**: wire that attaches to a component of a circuit

**Load**: device that converts electrical energy to another form, such as light, heat, sound or motion

**Model**: a simplified description of a complex system, showing only the essential elements

**Open circuit**: an attempt to build a circuit, which doesn’t work because at least one connection is not made

**Output**: the result of providing an input to a system

**Parallel circuit:** a circuit in which more than one load is wired directly to the same source

**Parallel:** Describes two lines that are always the same distance apart, and that never intersect

**Plan:** a method for expressing a future action

**Propeller-drive**: a car that is powered by a propeller

**Pull-chain switch:** A switch that is operated by pulling a string or chain, for example on a ceiling fan

**Pulley:** a wheel that transfers motion and energy to another pulley through a belt

**Push-button switch:** type of switch that is turned on when a button is held down, for example on a keyboard

**Redesign**: change a design to make it work better

**Rotary switch:** a switch that is operated by turning a component, for example on a table fan or dimmer

**Rotation**: motion along a circular path

**Series circuit:** a circuit in which the current passes through more than one load before returning to the source

**Skewer:** wooden stick that can be used as an axle

**Slide switch**: a switch that is operated by pushing a movable component back and forth

**Source**: a device that converts energy from some other form to electrical energy, such as a battery

**Switch**: a device that controls the flow of electricity

**Toggle switch**: a type of switch that can be flipped from one position to another, and locks in either position, such as a standard light switch

**Troubleshoot**: address an issue by identifying and fixing the cause

**Troubleshooting guide**: a book that tells you what to do when something doesn’t work

**Voltage**: a measure of electricity that describes the energy carried by moving charges