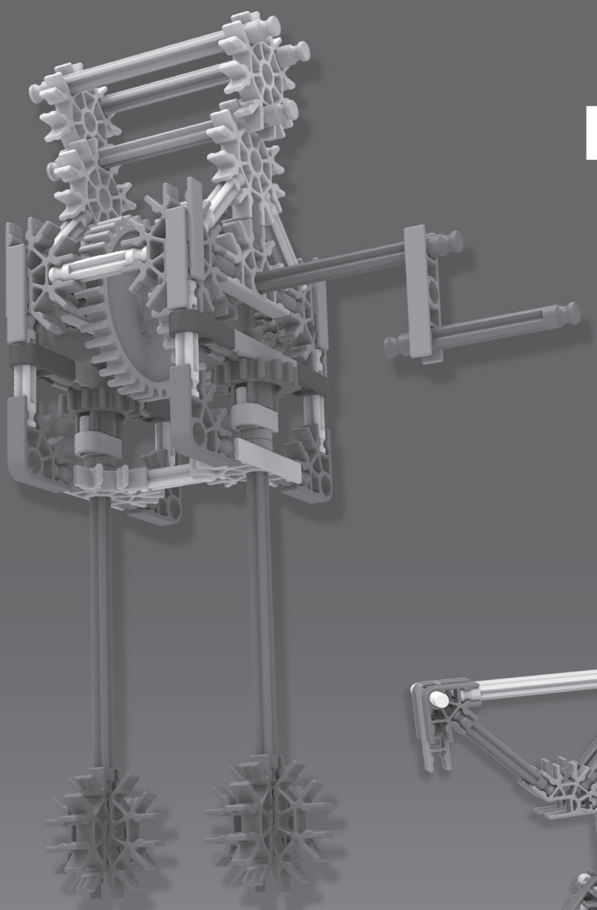
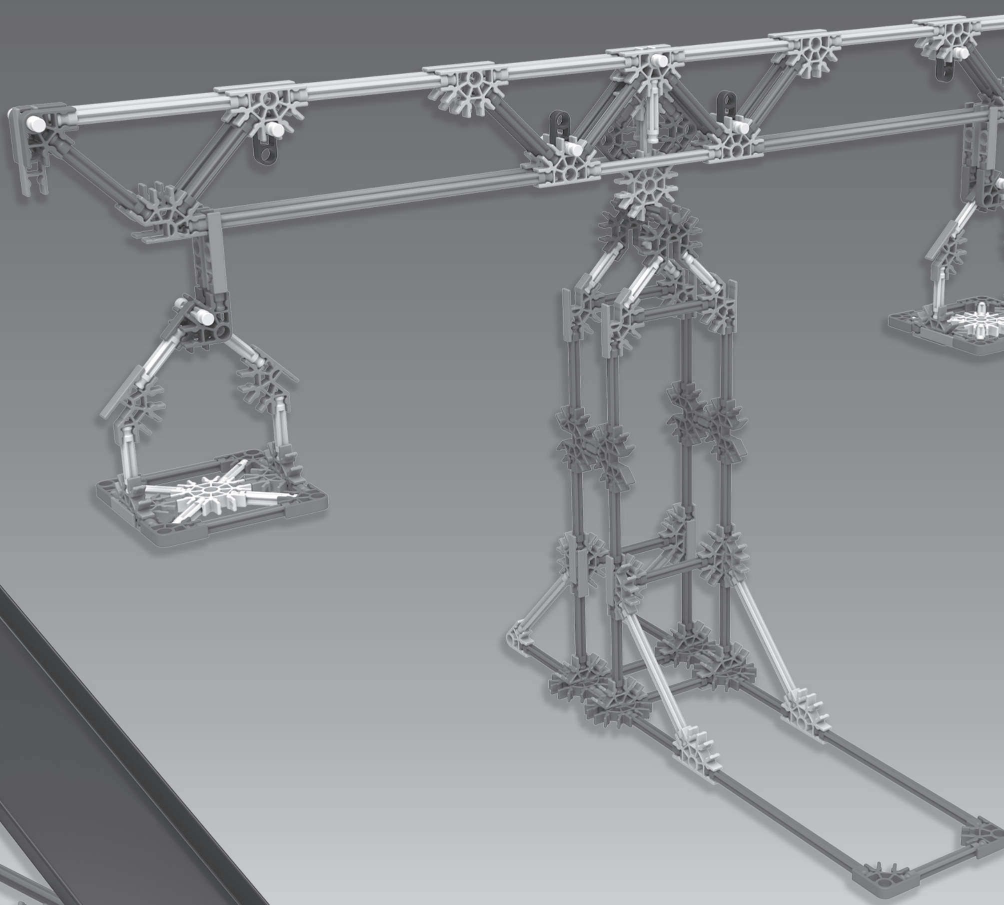
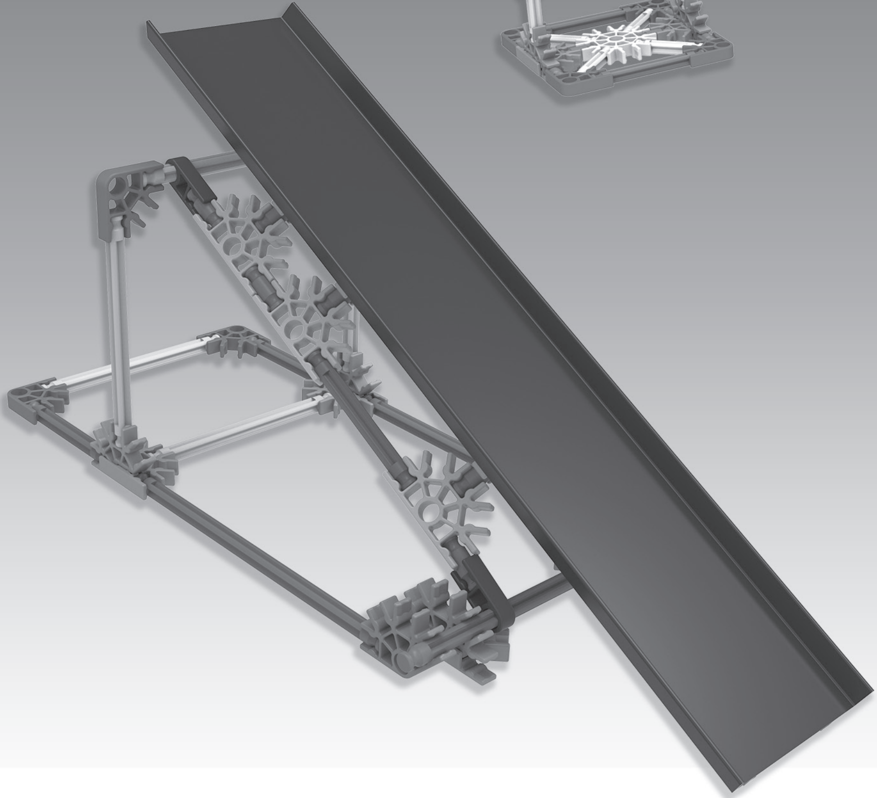
K'NEX® Education

# BUILDING SIMPLE MACHINES CLASS SET

# TEACHER'S GUIDE







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**A NOTE ABOUT SAFETY:**

Safety is of primary concern in science and technology classrooms. It is recommended that you develop a set of rules that governs the safe, proper use of K'NEX in your classroom. Safety, as it relates to the use of the string and rubber bands should be specifically addressed.

**⚠ CAUTIONS:**

Students should not overstretch or overwind their rubber bands. Overstretching and overwinding can cause the rubber band to snap and cause personal injury. Any wear and tear or deterioration of rubber bands should be reported immediately to the teacher. Teachers and students should inspect rubber bands for deterioration before each experiment. It is suggested that students wear protective eyewear when using rubber bands.

Caution students to keep hands and hair away from all moving parts. Never put fingers in moving gears or other moving parts.

## ⚠ WARNING:

CHOKING HAZARD - Small parts.
Not for children under 3 years.

## ⚠ AVERTISSEMENT :

DANGER D'ÉTOUFFEMENT - Pièces de petite taille.
Ne convient pas aux enfants de moins de 3 ans.

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# INTRODUCTION

## OVERVIEW

This Teacher's Guide has been developed to support you as your students investigate the K'NEX Building Simple Machines Class Set. In conjunction with the K'NEX materials and individual Student Journals, the information and resources included here can be used to build your students' understanding of scientific concepts and channel their inquiries into active and meaningful learning experiences.

### Building Simple Machines Class Set

This K'NEX construction set is designed to introduce students to the scientific concepts associated with Simple Machines. Students are provided with the opportunity to acquire skills using a hands-on, inquiry-based approach to information and concepts. Working cooperatively, students are encouraged to interact with each other as they build, investigate, discuss, and evaluate scientific principles in action.

### Teacher's Guide

Designed as a resource for the teacher, this guide provides a glossary of key terms and definitions, includes an overview of the concepts associated with Simple Machines, identifies student objectives for each unit, and offers plans and scripts to successfully present each simple machine model and its associated activities. Most of the units can be completed in 30-45 minutes. There are also extension activities that can be used to explore the concepts more deeply. We recommend that teachers review their curriculum and science education standards to identify which of the activities provided in this guide best meet their needs.

### Student Journals

It is expected that students will always have journals available for recording information. They should be encouraged to enter initial thoughts at the start of an inquiry – what they "think" will happen. These initial thoughts may be amended, based on their ongoing inquiry and analysis, until the students feel comfortable about drawing conclusions. Their journal entries will help make a connection between the models they have built, the experiments they have conducted, and how this information is applied to the real-world machines they use on a regular basis. The journals will also provide students with a place to practice making drawings and diagrams of systems. Finally, the journals will serve as a method of assessment for the Simple Machines unit. Journal Checklists are also included in the Teacher's Guide for each model and it's associated inquiry activities.

### Building Activities

If the class has not used K'NEX building materials, review the Building Tips on the back cover of the instructions booklet, particularly the information about the blue and gray connectors. Allow the students some time to explore the materials – it is crucial that they grasp the building concept at this stage so that frustrations are avoided later.

Provide some guidelines for keeping track of all the pieces in the set so that they will be available for future use. Remind students that they will need about 5 minutes at the end of the class period for clean up.

# Standards for Technological Literacy: Content for the Study of Technology

| **Standards for Technological Literacy: Content for the Study of Technology (Grades 3-5)**<br>*Students will develop an understanding of:* |
|---|
| **THE NATURE OF TECHNOLOGY** |
| Core Concepts of Technology |
| • *Systems* |
| • *Processes* |
| • *Requirements* |
| Relationships Among Technologies |
| • *Technologies integrated* |
| **DESIGN** |
| The Attributes of Design |
| • *Requirements of design* |
| Engineering Design |
| • *Engineering design process* |
| • *Creativity and considering all ideas* |
| • *Models* |
| The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation in Problem Solving. |
| • *Troubleshooting* |
| • *Invention and innovation* |
| • *Experimentation* |
| **ABILITIES FOR A TECHNOLOGICAL WORLD** |
| Apply Design Process |
| • *Collecting information* |
| • *Visualize a solution* |
| • *Test and evaluate solutions* |
| • *Improve a design* |

| Standards for Technological Literacy: Content for the Study of Technology (Grades 6-8)<br>*Students will develop an understanding of:* |
|---|
| **THE NATURE OF TECHNOLOGY** |
| Core Concepts of Technology |
| • *Systems* |
| • *Processes* |
| • *Requirements* |
| Relationships Among Technologies |
| • *Interaction of systems* |
| • *Knowledge from other fields of study and technology* |
| **DESIGN** |
| The Attributes of Design |
| • *Design leads to useful products and systems* |
| • *There is no perfect design* |
| Engineering Design |
| • *Brainstorming* |
| • *Modeling, testing, evaluating, and modifying* |
| The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation in Problem Solving. |
| • *Troubleshooting* |
| • *Invention and innovation* |
| • *Experimentation* |
| **ABILITIES OF A TECHNOLOGICAL WORLD** |
| Apply Design Process |
| • *Identify criteria and constraints* |
| • *Test and evaluate* |
| • *Make a product or system* |

*Used with permission of the ITEEA (www.iteea.org)*

# NSES Content Standards Alignments

| **National Science Education Standards (Grades K - 4)**<br>*Students will develop an understanding of:* |
|---|
| **UNIFYING CONCEPTS AND PROCESSES** |
| • *Systems, order, and organization* |
| • *Evidence, models, and explanation* |
| • *Change and measurement* |
| • *Form and function* |
| **PHYSICAL SCIENCE** |
| • *Properties of objects and materials* |
| • *Position and motion of objects* |
| **SCIENCE AND TECHNOLOGY** |
| • *Abilities of technological design* |
| • *Understanding about science and technology* |
| **National Science Education Standards (Grades 5 - 8)**<br>*Students will develop an understanding of:* |
| **UNIFYING CONCEPTS AND PROCESSES** |
| • *Systems, order, and organization* |
| • *Evidence, models, and explanation* |
| • *Change and measurement* |
| • *Form and function* |
| **SCIENCE AS INQUIRY** |
| • *Abilities necessary to do scientific inquiry* |
| • *Understanding about scientific inquiry* |
| **PHYSICAL SCIENCE** |
| • *Motions and Forces* |
| • *Transfer of Energy* |
| **SCIENCE AND TECHNOLOGY** |
| • *Abilities of technological design* |
| • *Understanding about science and technology* |

# NCTM Standards Alignments

| National Council of Teachers of Mathematics Education<br>Standards and Expectations for Grades 3 - 5 |
| --- |
| **NUMBER AND OPERATIONS** |
| Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Understand numbers, ways of representing numbers, relationships among numbers, and number systems.* |
| • *Understand meanings of operations and how they relate to one another.* |
| • *Compute fluently and make reasonable estimates.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Understand numbers, ways of representing numbers, relationships among numbers, and number systems. |
| • *Understand the place-value structure of the base-ten number system and be able to represent and compare whole numbers and decimals.* |
| • *Develop understanding of fractions as parts of unit wholes, as parts of a collection, as locations on number lines, and as divisions of whole numbers.* |
| • *Use models, benchmarks, and equivalent forms to judge the size of fractions.* |
| • *Recognize and generate equivalent forms of commonly used fractions, decimals, and percents.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Understand meanings of operations and how they relate to one another. |
| • *Understand various meanings of multiplication and division.* |
| • *Understand the effects of multiplying and dividing whole numbers.* |
| • *Identify and use relationships between operations, such as division as the inverse of multiplication, to solve problems.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Compute fluently and make reasonable estimates. |
| • *Develop fluency with basic number combinations for multiplication and division and use these combinations to mentally compute related problems, such as 30 × 50.* |
| • *Develop fluency in adding, subtracting, multiplying, and dividing whole numbers.* |
| • *Develop and use strategies to estimate computations involving fractions and decimals in situations relevant to students' experiences.* |
| • *Select appropriate methods and tools for computing with whole numbers from among mental computation, estimation, calculators, and paper and pencil according to the context and nature of the computation and use the selected method or tools.* |
| **ALGEBRA** |
| Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Understand patterns, relations, and functions.* |
| • *Represent and analyze mathematical situations and structures using algebraic symbols.* |
| • *Use mathematical models to represent and understand quantitative relationships.* |
| • *Analyze change in various contexts.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Understand patterns, relations, and functions. |
| • *Represent and analyze patterns and functions, using words, tables, and graphs.* |

| |
|---|
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Represent and analyze mathematical situations and structures using algebraic symbols. |
| • *Represent the idea of a variable as an unknown quantity using a letter or a symbol.* |
| • *Express mathematical relationships using equations.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Use mathematical models to represent and understand quantitative relationships. |
| • *Model problem situations with objects and use representations such as graphs, tables, and equations to draw conclusions.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Analyze change in various contexts. |
| • *Investigate how a change in one variable relates to a change in a second variable.* |
| • *Identify and describe situations with constant or varying rates of change and compare them.* |
| **MEASUREMENT STANDARD** |
| Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Understand measurable attributes of objects and the units, systems, and processes of measurement.* |
| • *Apply appropriate techniques, tools, and formulas to determine measurements.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Understand measurable attributes of objects and the units, systems, and processes of measurement. |
| • *Understand such attributes as length, and select the appropriate type of unit for measuring each attribute.* |
| • *Understand the need for measuring with standard units and become familiar with standard units in the customary and metric systems.* |
| • *Carry out simple unit conversions, such as from centimeters to meters, within a system of measurement.* |
| • *Understand that measurements are approximations and how differences in units affect precision.* |
| **DATA ANALYSIS AND PROBABILITY** |
| Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.* |
| • *Select and use appropriate statistical methods to analyze data.* |
| • *Develop and evaluate inferences and predictions that are based on data.* |
| • *Understand and apply basic concepts of probability.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them. |
| • *Collect data using observations, surveys, and experiments.* |
| • *Represent data using tables and graphs such as line plots, bar graphs, and line graphs.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Select and use appropriate statistical methods to analyze data. |
| • *Describe the shape and important features of a set of data and compare related data sets, with an emphasis on how the data are distributed.* |
| Grades 3 - 5 Expectations: In grades 3 - 5 all students should:<br>Develop and evaluate inferences and predictions that are based on data. |
| • *Propose and justify conclusions and predictions that are based on data and design studies to further investigate the conclusions or predictions.* |

| PROCESS STANDARDS |
|---|
| Problem Solving<br>Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Build new mathematical knowledge through problem solving.* |
| • *Solve problems that arise in mathematics and in other contexts.* |
| • *Apply and adapt a variety of appropriate strategies to solve problems.* |
| • *Monitor and reflect on the process of mathematical problem solving.* |
| Reasoning and Proof<br>Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Recognize reasoning and proof as fundamental aspects of mathematics.* |
| • *Select and use various types of reasoning and methods of proof.* |
| Communication<br>Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Organize and consolidate their mathematical thinking through communication.* |
| • *Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.* |
| • *Analyze and evaluate the mathematical thinking and strategies of others.* |
| • *Use the language of mathematics to express mathematical ideas precisely.* |
| Connections<br>Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Recognize and use connections among mathematical ideas.* |
| • *Recognize and apply mathematics in contexts outside of mathematics.* |
| Representation<br>Instructional programs from pre-kindergarten through grade 12 should enable all students to: |
| • *Create and use representations to organize, record, and communicate mathematical ideas.* |
| • *Select, apply, and translate among mathematical representations to solve problems.* |
| • *Use representations to model and interpret physical, social, and mathematical phenomena.* |

# Common Core Standards Alignments

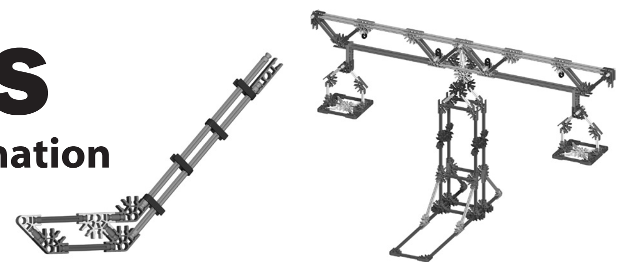
| Common Core State Standards for Mathematics in Grades 3 - 5 |
|---|
| **GRADE 3** |
| Operations and Algebraic Thinking |
| • *Represent and solve problems involving multiplication and division.* |
| • *Understand properties of multiplication and the relationship between multiplication and division.* |
| • *Multiply and divide within 100.* |
| • *Solve problems involving the four operations, and identify and explain patterns in arithmetic.* |
| Number and Operations in Base Ten |
| • *Use place value understanding and properties of operations to perform multi-digit arithmetic.* |
| Number and Operations - Fractions |
| • *Develop understanding of fractions as numbers.* |
| Measurement and Data |
| • *Solve problems involving measurement .* |
| • *Represent and interpret data.* |
| **MATHEMATICAL PRACTICES - ASSOCIATED WITH MATHEMATICS AT ALL GRADE LEVELS** |
| *1. Make sense of problems and persevere in solving them.* |
| *2. Reason abstractly and quantitatively.* |
| *3. Construct viable arguments and critique the reasoning of others.* |
| *4. Model with mathematics.* |
| *5. Use appropriate tools strategically.* |
| *6. Attend to precision.* |
| *7. Look for and make use of structure.* |
| *8. Look for and express regularity in repeated reasoning.* |
| **GRADE 4** |
| Operations and Algebraic Thinking |
| • *Use the four operations with whole numbers to solve problems.* |
| • *Gain familiarity with factors and multiples.* |
| • *Generate and analyze patterns.* |
| Number and Operations in Base Ten |
| • *Use place value understanding and properties of operations to perform multi-digit arithmetic.* |
| Number and Operations - Fractions |
| • *Understand decimal notation for fractions, and compare decimal fractions.* |
| Measurement and Data |
| • *Solve problems involving measurement and conversion of measurements from a larger unit to a smaller unit.* |
| • *Represent and interpret data.* |

| GRADE 5 |
| --- |
| Operations and Algebraic Thinking |
| • *Write and interpret numerical expressions.* |
| • *Analyze patterns and relationships.* |
| Number and Operations in Base Ten |
| • *Perform operations with multi-digit whole numbers and with decimals to hundredths.* |
| Measurement and Data |
| • *Convert like measurement units within a given measurement system.* |
| • *Represent and interpret data.* |
| Geometry |
| • *Graph points on the coordinate plane to solve real-world and mathematical problems.* |

*Authors: National Governors Association Center for Best Practices, Council of Chief State School Officers; Title: Common Core State Standards Mathematics; Publisher: National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington D.C.; Copyright Date: 2010*

# LEVERS

## Background Information



## OBJECTIVES

### Students will:

1. Describe the characteristics of levers.
2. Understand how levers work.
3. Investigate the relationships between force, distance, direction and work.
4. Understand the differences between the three classes of levers and recognize how they are used.
5. Construct examples of different types of levers and demonstrate how they function.
6. Analyze objects/tools in terms of their application as levers.

## KEY TERMS and DEFINITIONS for the teacher

The following is intended as a resource for the teacher. The age of the students, their abilities, their prior knowledge, and the curriculum requirements will determine which of these terms and definitions you introduce into your classroom activities. These terms are not presented as a list for students to copy and memorize. Rather, they should be used to formalize and clarify the operational definitions your students develop during their investigations.

**Simple Machine:**
A simple tool that makes work easier to do. Most simple machines have only one moving part. Simple machines make work easier by changing the way in which the work is done. They do not change the amount of work that is needed to do the job.

**Lever:**
A rigid beam, bar or rod that turns, or rotates, about a fixed point called the fulcrum to complete a task (do work.)

**Fulcrum:**
A fixed point that allows the beam to rotate around it. It can occur at any point along the lever.

**Work:**
The task being completed while using the lever. In science, work refers to the use of force to move a load (object) through a distance. It can be defined as follows:

$$W = F \times d$$

Where **W** = work

**F** = the force (effort) applied to the task

**d** = the distance through which the force is applied

**NOTE:** If the object has not moved, work has not been done.

**Force:**
Any kind of push or pull applied to an object.

**Effort:**
The force that is applied to move one component of a simple machine (i.e.: the force that is applied to do work.) This force is called the effort force.

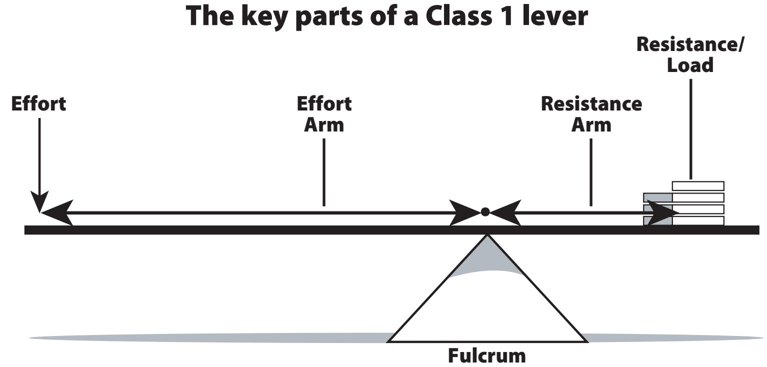
**Effort Arm (EA):**
The distance on the lever extending from the fulcrum to the point where the effort is applied.

**Resistance:**
The force exerted by the object (load) upon which one is trying to do work; it works against the effort.

**Resistance Arm (RA):**
The distance on the lever extending from the fulcrum to the point where the resistance is applied.

**Load:**
The object (weight) moved or the resistance that is overcome with a lever. The load exerts a force (resistance) against the lever. For example: the weight of a heavy object to be moved or a piece of paper that is resisting the cutting action of the scissor blades.

**The key parts of a Class 1 lever**




**Friction:**
The force caused when 2 surfaces rub together as an object moves.

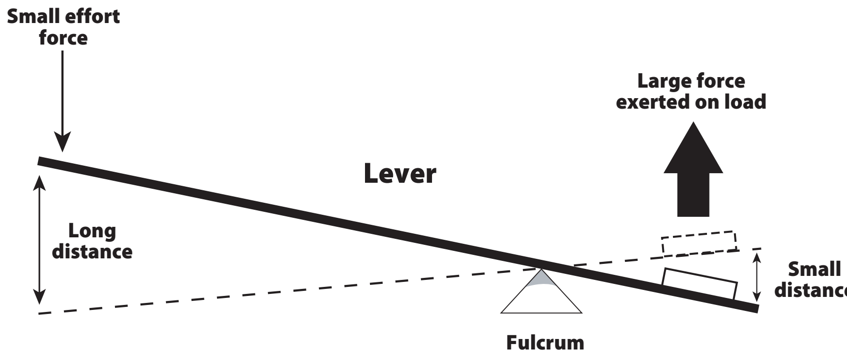
**Mechanical Advantage (MA):**
A mathematical calculation that indicates how many times the simple machine multiplies the effort force. For a lever it can be calculated using the following formula:

$$\frac{\textbf{Length of Effort Arm (EA)}}{\textbf{Length of Resistance Arm (RA)}} = \textbf{MA}$$

Mechanical Advantage is always expressed as a number without a unit. For example: MA = 2.

## KEY CONCEPTS

The following summarizes some of the key concepts associated with levers and is offered here as **a resource for the teacher.**




- A lever pivots on one fixed point – up and down, or side to side.
- To use a lever, effort is applied to the effort arm in the form of a push or pull. The lever then transfers this force to overcome a resistance or to move a load.
- A lever can make work easier in the following ways:

### Multiplying the force being applied.

- This occurs when the effort arm of the lever is longer than the resistance arm. A small effort force, applied over a long distance, is multiplied by the machine to move a load through a small distance. What is lost in distance moved is gained in force.
- The longer the effort arm of the lever, the more the lever multiplies the effort force.

***Examples:***

*Opening a soft drink bottle with a bottle opener.*

*Pulling a nail out of a piece of wood with a claw hammer.*

*Moving a load of sand with a wheelbarrow.*

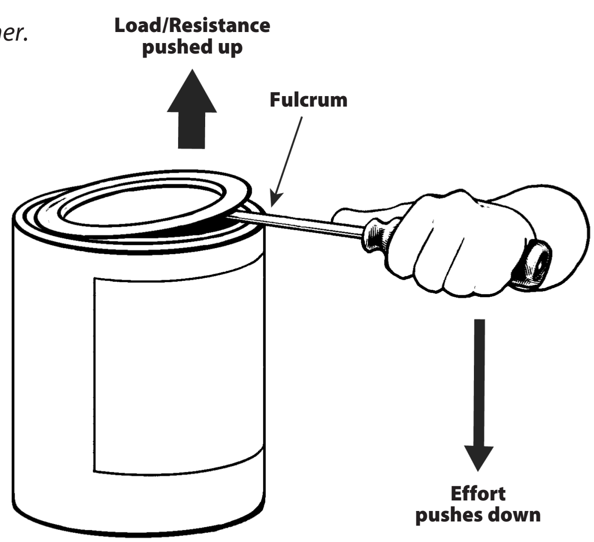
### Changing the direction of a force.

- When the fulcrum is located between the effort force and the resistance, (a 1st Class lever – see below,) the lever always reverses the direction of the effort force.

***Examples:***

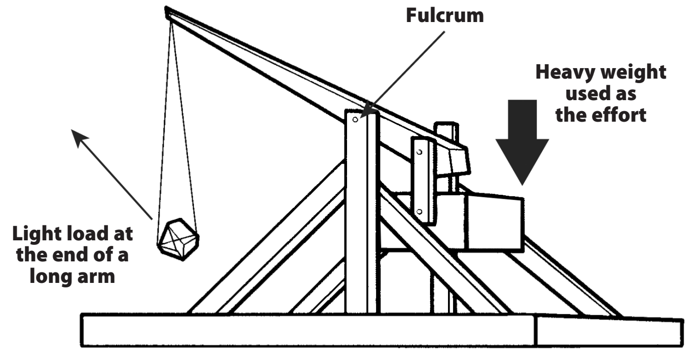
*Pushing down on one side of a seesaw results in the opposite side moving upwards and allows one child to easily lift another.*

*Pushing down on a lever lifts the lid on a can of paint. It is easier to push down than to pull up to raise the lid.*



**Multiplying the distance (rate) and thus speed over which the job is done.** This requires a 1st or 3rd Class lever with a long resistance arm and a short effort arm. For example, medieval devices, known as trebuchets, were used to throw large boulders at castle walls during sieges.

The trebuchet was a giant 1st Class lever in which the fulcrum was closer to the effort force. A massive effort force was pulled downwards several feet causing the long resistance arm of the trebuchet to move 20' or more at a high rate of speed. This motion propelled the small load a great distance at an even higher speed. Trebuchets caused enormous damage because they were able to toss boulders at castle walls at speeds in excess of 100 mph.




The oars on a rowing boat (1st Class), a fishing rod (3rd Class) and a hockey stick (3rd Class) use the same principle.

Visit http://www.flying-pig.co.uk/Pages/lever2.htm to see a trebuchet in action.

Visit http://www.pbs.org/wgbh/nova/lostempires/trebuchet/builds.html to see photos of the reconstruction of a trebuchet.

**The Principle of Levers** identifies a relationship between effort, resistance and distance from the fulcrum. This principle states that a lever is in a state of equilibrium when:

**Effort x its distance from the fulcrum =**

**Resistance (load) x its distance from the fulcrum**

or **E x EA = R x RA**

Where: **E** = Effort force **EA** = Length of Effort Arm
**R** = Resistance **RA** = Length of Resistance Arm

Using this formula you can determine how to obtain a state of equilibrium when using a particular lever arrangement.

For example:

In the Class 1 Lever shown below, **(Fig. 1)** the applied effort and the resistance are both the same distance from fulcrum. Raising the resistance (load) requires an effort force equal to the weight of the load.

In the Class 1 Lever shown below, **(Fig. 2)** the applied effort is twice as far from the fulcrum as the resistance (load). Raising the load requires an effort force equal to one-half the weight of the load. Similarly, if the applied effort is three times as far from the fulcrum as the load, raising that load will require a force equal to one-third of the load's weight.

**Fig. 1**

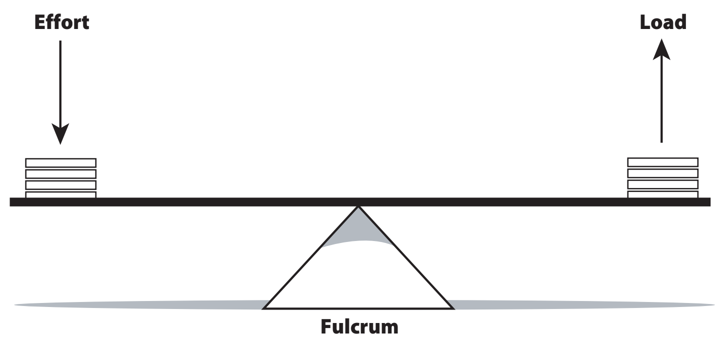
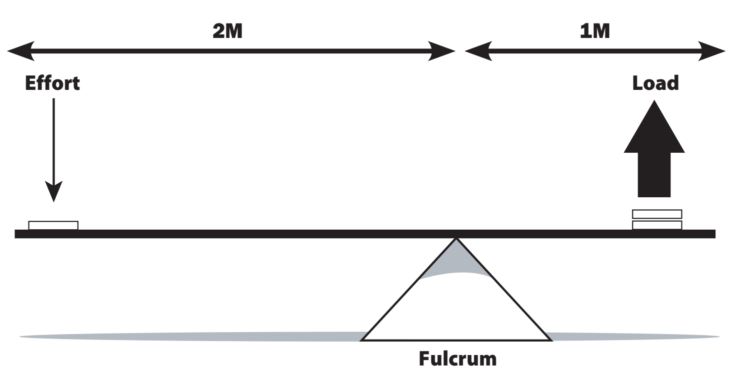



**Fig. 2**



## There are three basic types of levers: 1st Class, 2nd Class and 3rd Class.

They all share the common components of a rigid rod or beam, fulcrum, effort and resistance (load). They differ only in the relative positions of the fulcrum, effort and resistance.

### 1st Class levers

Characteristics:

(a) The fulcrum is always positioned between the effort force and the resistance.

(b) This class of lever always changes the direction of the effort force, so that the effort and the resistance move in opposite directions: a downward push on one side of the lever can result in an upward push or pull on the other. **(Fig. 3)**

(c) Depending on which is closer to the fulcrum, the resistance or the effort, some 1st Class levers multiply the effort force, while others increase the distance the load is moved.

Generally:

- **The longer the effort arm, the less effort is needed to move the load.**
- **The longer the load or resistance arm, the more force is needed to move the load, but it moves further, faster.** (The trebuchet is an example of this.)

Fig. 3

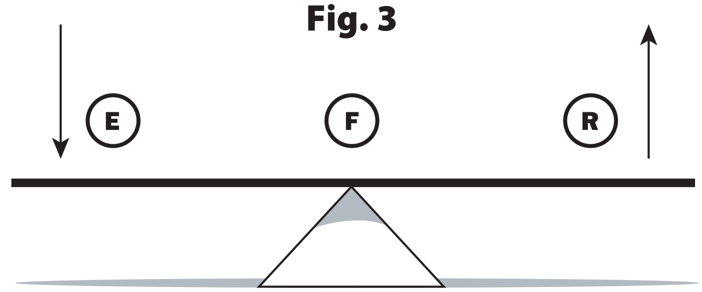



Fig. 4

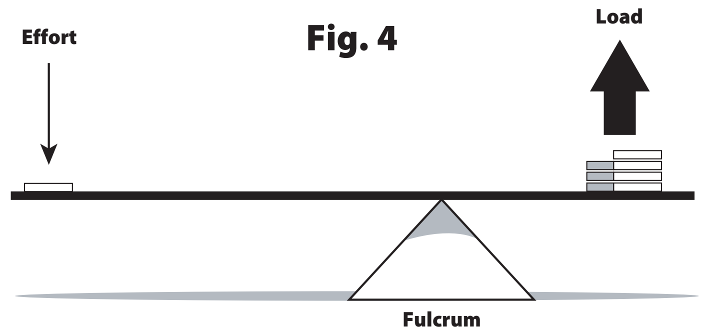
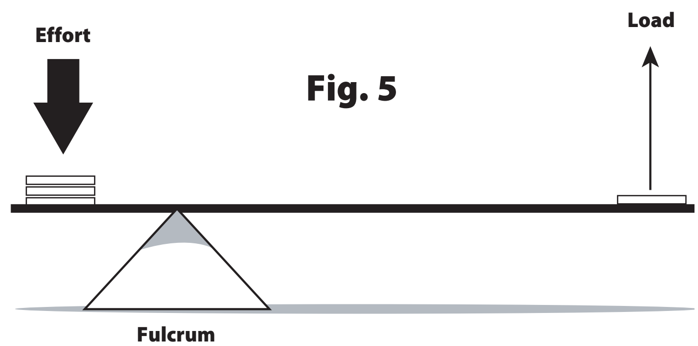


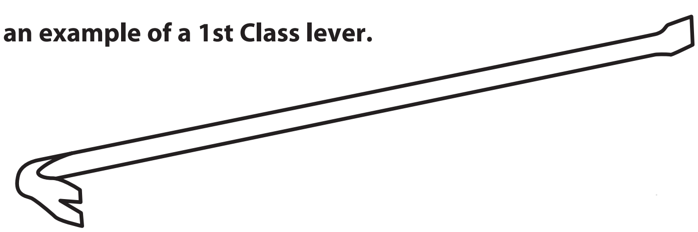

Fig. 5




**Examples of 1st Class levers:**

Seesaw; crowbar; the claw of a claw hammer; oars on a rowboat; scissors (2 connected 1st Class levers).

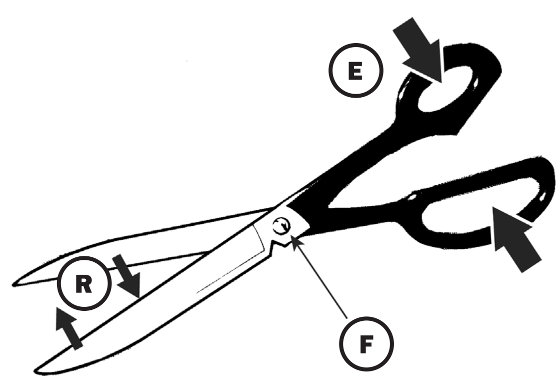
**A crowbar is an example of a 1st Class lever.**



**A pair of scissors is an example of two 1st Class levers working together.**

Squeezing the handles together produces the effort force, the hinge is the fulcrum, and the resistance of the material being cut is the load.

Note that the strongest cutting action is nearest the hinge. Arrows show the direction of the forces.



## 2nd Class levers

Characteristics:

(a) The resistance (load) is between the effort and the fulcrum.

(b) The effort and load move in the same direction – lift up the lever and the load also moves in an upward direction. **(Fig. 6)**

(c) 2nd Class levers always increase the effort force to make work easier because the resistance (load) is always closer to the fulcrum than the effort. **This means that the effort arm is always longer than the resistance arm; the longer the effort arm, the more the effort force is increased and the easier it is to move the load.** With a 2nd Class lever it is possible to move a large load with a small effort.

**Fig. 6**

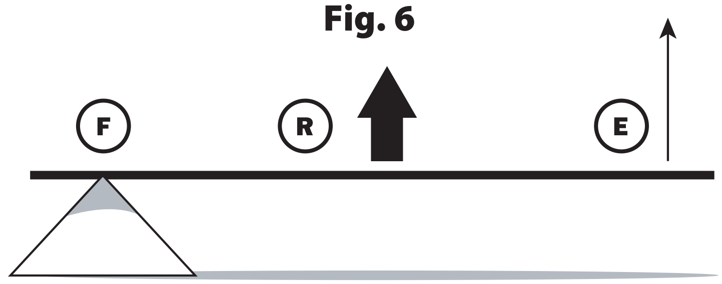
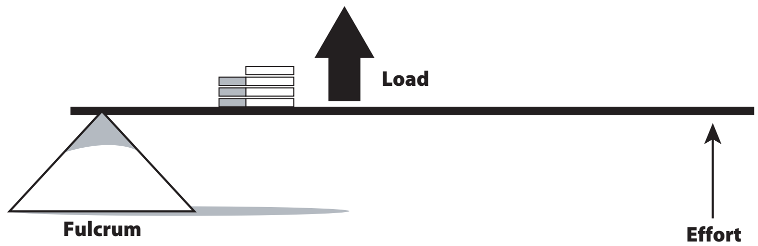
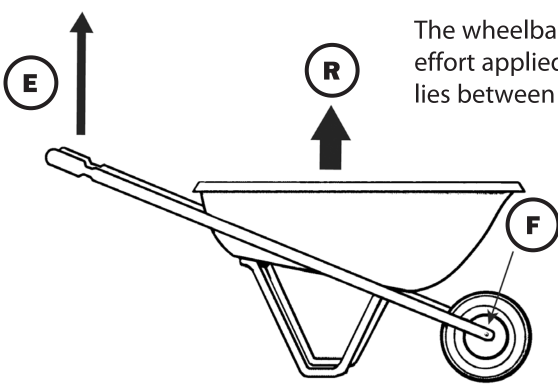



**Fig. 7**

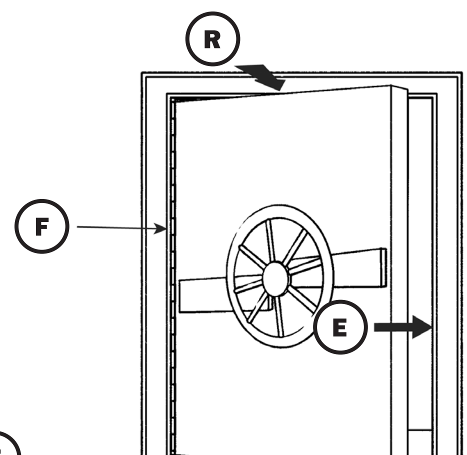


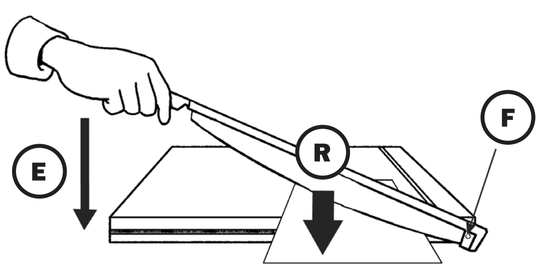

**Examples of 2nd Class levers:**

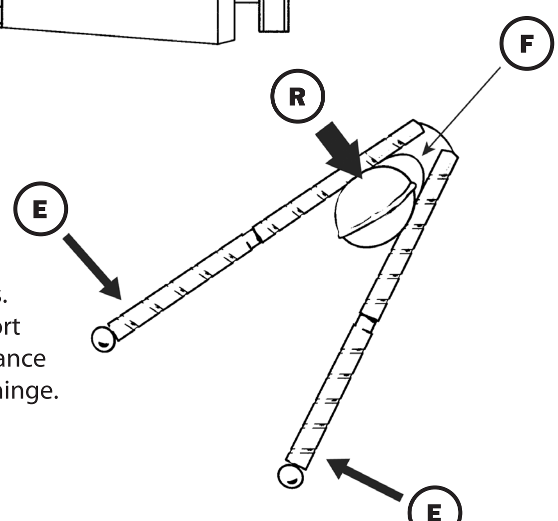
Wheelbarrow; paper cutter (guillotine); hinged door; nutcrackers (two 2nd Class levers.)




The wheelbarrow is a 2nd Class lever with the wheel acting as the fulcrum and the effort applied at the handles. The load is placed in the pan of the wheelbarrow, which lies between the effort and the fulcrum. **(Fig. 7)**




The nutcracker comprises two 2nd Class levers. The effort is applied by squeezing the two effort arms together by a hand; the load is the resistance of the nutshell to cracking; the fulcrum is the hinge.

## 3rd Class levers

Characteristics:

(a) The effort is between the fulcrum and the resistance/ load.

(b) The effort and load move in the same direction. **(Fig. 8)** For example, when you swing a baseball bat, a tennis racquet, or a golf club forward to hit a ball, the ball moves forward too.

(c) 3rd Class levers increase distance and speed at the expense of force. Applying effort close to the fulcrum requires a great deal of force and the effort arm will only move through a small distance. The end of the resistance arm of the lever, however, moves through a greater distance, at a faster speed but with less force. In **Fig. 9** the resistance (load) is located twice as far from the fulcrum as the effort. The load moves twice as far, in the same amount of time, as the effort but it requires twice as much applied effort force as moving it without the lever.

For example, raising a fish with a fishing rod actually requires more effort force than just lifting the fish using only a hand-held line. However, a fishing rod helps by lifting up the fish quickly. A small movement of your hands near the fulcrum produces a large movement at the tip of the rod, but both move in the same period of time. As a result, the tip of the rod (and the fish attached to it) actually moves much more quickly than the hands and this quick action can help land the fish before it escapes. **(Fig. 10)**

(**NOTE:** This also means that a quick snap of the wrist will cast the lure or the worm far out into the pond or river.)

**The closer the effort force is to the fulcrum, the faster the resistance moves.**

**Fig. 8**

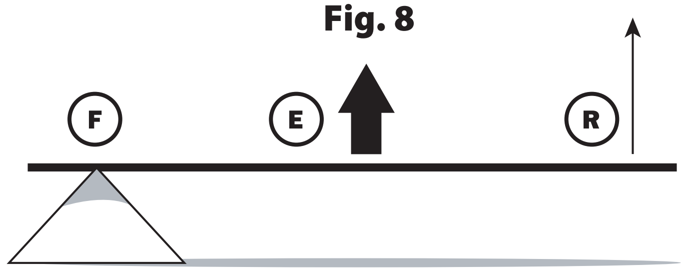



**Fig. 9**

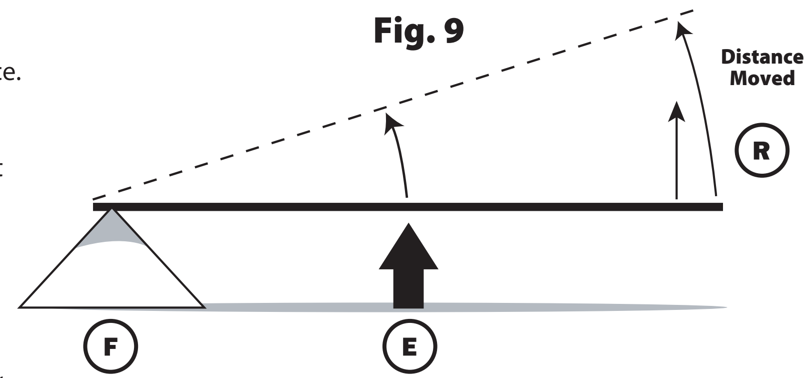
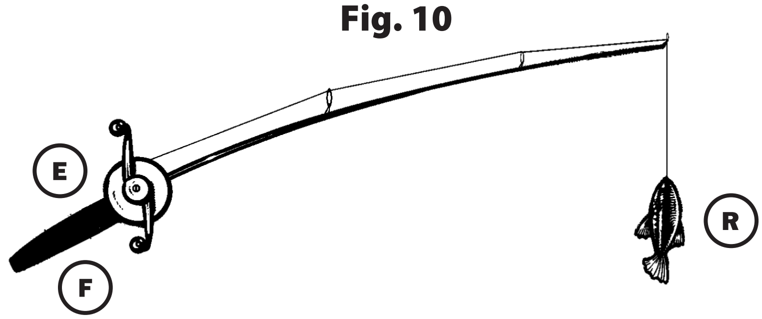



**Fig. 10**

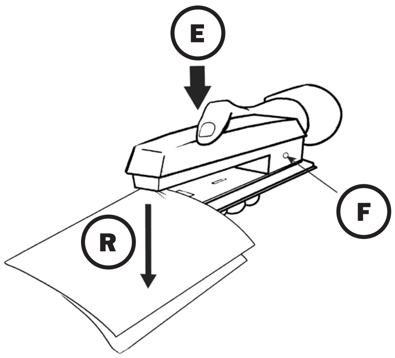


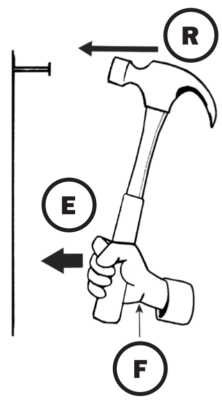
**Examples of 3rd Class levers:**

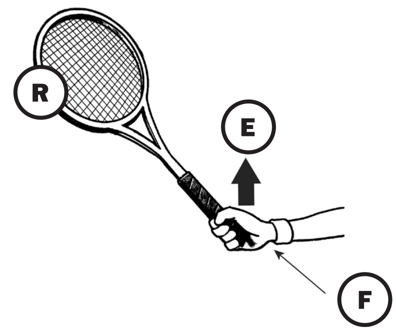
Stapler squeezed by hand*; hammer driving home a nail; fishing rod; tennis racquet; baseball bat; golf club.

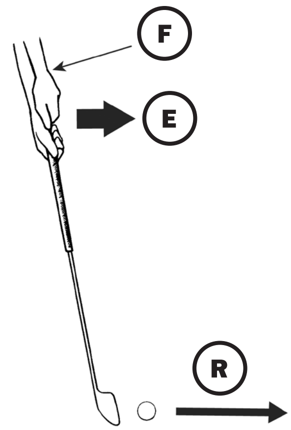
Tweezers and ice tongs are examples of two 3rd Class levers working together.

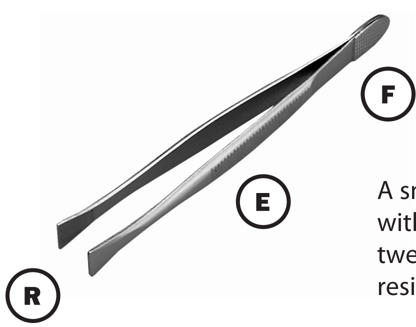
(* If the stapler is placed on a hard surface and operated by hitting down on the end by hand it is a 2nd Class lever.)




A small movement of the fingers squeezing the two arms together with considerable effort produces a long movement at the tips of the tweezers/ice tongs allowing them to grip an object. The load is the resistance of the object.

## Useful Web Sites

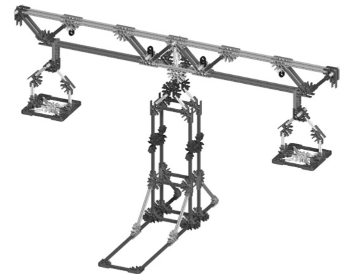
http://www.enchantedlearning.com/physics/machines/Levers.shtml
This web site has some very simple animated drawings of the different types of levers in action.

www.coe.uh.edu/archive/
The University of Houston archive of lessons. Go to: Collection > Science > Lesson Plans > Simple Machines.

www.mos.org/sln/Leonardo/InventorsToolbox.html.
A good general site covering levers and other simple machines.

# THE BALANCE:

## An example of a 1st Class lever



## OBJECTIVES

### Students will:

1. Identify the fulcrum, load (resistance), and effort force on a balance (lever).
2. Identify the effort arm and resistance arm on a balance (lever).
3. Describe why the balance is an example of a first class lever.
4. Discover by experimentation that a first class lever multiplies force and changes the direction of force.
5. Through experimentation, investigate how the locations of the effort and resistance on the balance arms are related.

## MATERIALS

### Each group of students will need:

- Building Instructions Booklet and K'NEX parts
- Dot stickers or pieces of masking tape
- Small paper cups (3 oz. bathroom cups)
- Small classroom objects that will fit in the cups (binder clips, erasers, or chalk)
- Student Journals
- Rulers
- Scissors
- A pre-made K'NEX Balance for demonstration
- Pennies minted after 1982 (Enough to provide each group with approximately 30 pennies)

**NOTE:** Refer to pages 12-18 of this guide to access the Background Information provided about levers. The Background Information section provides objectives, key terms and definitions, diagrams, and key concepts related to levers. This information will help you to refresh your understanding of levers and lever classes before you begin this lesson with students.

## PROCEDURE

### Introduction

- Ask students to complete the following statement. If two people get on a seesaw and it stays level, the seesaw is _______________.

  ***Students should respond that the seesaw is balanced.***

- Ask them why they think the seesaw (lever) balances.

  ***Students may answer that both people weigh the same amount. Some may realize that it could also be related to the distance that they are each sitting from the fulcrum.***

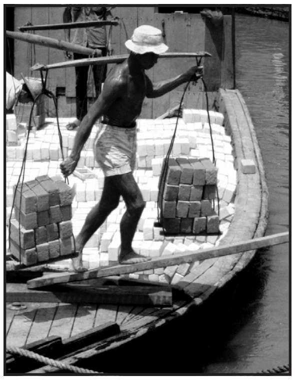
- Discuss how a balance allows you to compare the mass of two different objects. Show the K'NEX Balance and highlight the balance trays. Describe how stores once used balances to determine how much candy, flour, or fruit a customer purchased. The store owner placed the goods on one balance tray and small metal masses on the other tray until the balance was level. They would then add up the masses to see how much was purchased.

- Balances can also be used to help people carry heavy loads more easily. Imagine carrying 5 gallons of water in a single bucket. You would have to lean to one side to keep your balance. How could you make the task easier if you had more buckets available.

  ***Students should be helped to understand that the large load can be split into two equal parts so that the weight of the load is evenly distributed and balanced across their bodies.***

  ***If they put 2 ½ gallons of water in two buckets, they would be balanced and there would be less force on each of their arms.***

- For centuries, people have used a rod or yoke across their shoulders (as shown in the picture below) to help them balance heavy loads so they will be easier to carry.



- Ask the students to draw a picture of a system that is balanced and/or describe a situation where a balance is used in the real world in their journals.
- Explain that they will build a model of a balance to continue their investigation into levers. They will identify the lever class the balance represents and observe what happens when they move the positions of the load and the effort on the lever.

## BUILDING ACTIVITY

- Organize the class into teams of 2 – 3 students each. Provide each team with an Instruction Booklet and K'NEX pieces from the K'NEX Education Building Simple Machines Class Set.
- Invite the students to build the **BALANCE** model (pages 2-5 of the Building Instructions Booklet).
- Discuss the similarities between the K'NEX Balance model and seesaws in a playground.

## INQUIRY ACTIVITY: How do we balance a balance?

- **Teacher Note:** Each side of the balance is the same so there is no way to distinguish between the load side and the effort side. Designate the right side of the balance the load side and the left side the effort side. You may suggest students place a label on each side of the balance. Remind students to maintain careful records of their observations throughout this lesson.
- Ask the students to use stickers or tape to label the parts of the balance.

  **F** - Fulcrum    **L** - Load (Resistance)    **E** - Effort

- Instruct students to place a labeled diagram of their balance in their journals.
- Ask students which lever class the balance demonstrates and why. Discuss their input to ensure all groups are in agreement. Ask students to write their answer and explanation in their journals.

  ***(1st Class Lever! The fulcrum is between the effort and the load on first class levers.)***

- Inform students that the distance from the fulcrum to the load is called the **resistance arm** of the lever. The distance from the fulcrum to the effort force is called the **effort arm**. Have students label these arms with masking tape on their model and in their journals.
- Use the following script to help the students discover how to balance the balance.

**1.** (a) Instruct students to place a ring of tape on the bottom of two small cups and attach the cups to the balance trays (students may need scissors to trim the sides of the cups to fit on the trays). Students will slide the trays to the ends of the balance arms. Why do the balance arms remain level?

***The forces acting on either arm are equal. The tray and cup on the right side match the tray and cup on the left side.***

(b) What happens when one arm of the model is given a small push downward? How does the other arm of the balance respond to the push? Explain your observations.

***The balance arms move because the forces acting on the two arms are unequal. The balance arm that was pushed moves in the same direction it is pushed. The other arm moves in the opposite direction so this simple machine changes the direction of force.***

(c) Discuss how this activity demonstrates an object will remain stationary, or at rest, until a force acts on it.

***With the trays at the ends of the arms, the system was balanced and there was no motion. The arms of the balance only moved when a force was applied to one arm.***

**2.** Ask students to place pennies in the cup on the load side of the model. Ensure both of the trays are at the ends of the balance arms.

(a) What happens to the balance?

***The tray with the pennies goes down while the other side goes up. This reinforces the fact that this simple machine changes the direction of force.***

(b) Why does this happen?

***The pennies add a force to one side of the balance. Help students to understand that this is the result of unbalanced forces in action.***

**3.** How can you balance the forces acting on the model?

***Students may either add or remove coins in order to equalize the weights on both sides. The students should be encouraged to discuss their observations using the terms balanced and unbalanced forces.***

**4.** Ask students to move the trays to the end of the balance arms and to place four (4) pennies in the cup on the load side and two pennies on the effort side of the balance. Ask them to find a way to balance the model without adding or removing coins. Offer the following suggestions if necessary.

(a) Slide the hanging trays, one at a time, closer to the fulcrum.

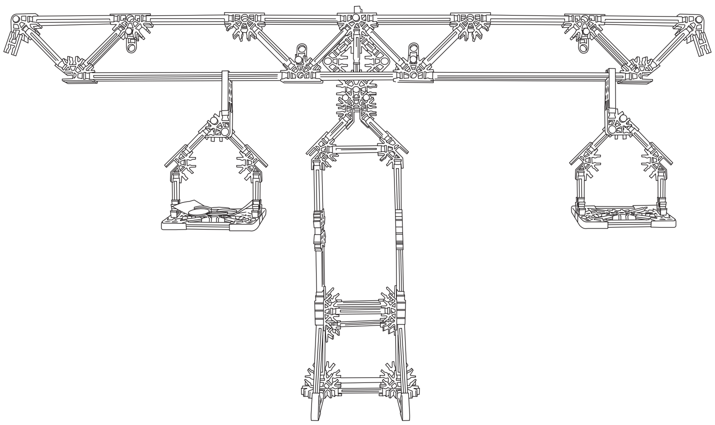
(b) What happens?

(c) Why does this happen?

***The balance arms become level if the students move the tray with more pennies closer to the fulcrum. Remind students that effort applied a long distance from the fulcrum can lift a heavier load close to the fulcrum. If a small effort force (2 pennies) can lift a heavier load (4 pennies), the simple machine is demonstrating its ability to multiply force.***

**5.** Distribute a copy of the table below for students to record their results for the next activity. As students complete the activity they will be adding pennies to balance various sized loads. (Inform students that the last penny they add to the effort tray may cause the effort arm to drop slightly below level. Count that last penny as the one that balances the system.) Instructions for the activity are on the next page.

| LOAD TRAY | | EFFORT TRAY | |
|---|---|---|---|
| Number of Pennies | Distance from Fulcrum | Number of Pennies | Distance from Fulcrum |
| **8** | **10cm** | | **10cm** |
| **8** | **10cm** | | **15cm** |
| **8** | **10cm** | | **20cm** |
| **12** | **10cm** | | **10cm** |
| **12** | **10cm** | | **15cm** |
| **12** | **10cm** | | **20cm** |
| **16** | **10cm** | | **10cm** |
| **16** | **10cm** | | **15cm** |
| **16** | **10cm** | | **20cm** |



6. Tell the students that they will be completing an experiment with their balance. They will determine what happens when the effort tray is moved further and further from the fulcrum.
   (a) Place 8 pennies in the load tray. Using a ruler, slide the tray until it is 10 cm from the fulcrum. Place the effort tray 10 cm from the fulcrum and add coins to the effort tray until the balance is level. Enter the number of pennies added to the data table. Is the number what you expected? Explain why.
   (b) Move the effort tray 5 cm further out on the effort arm and add or remove pennies from the effort tray to balance the system. Enter the number of pennies in the chart. Is the number what you expected? Explain why.
   ***Answers will vary. The machine multiplies force so it should take fewer and fewer pennies as the tray moves away from the fulcrum.***
   (c) Move the effort tray another 5 cm and repeat the experiment.
   (d) Repeat steps a, b, and c for 12 and 16 pennies to complete the remainder of the data table.
   (e) What does the information gathered on the data tell you about the operation of a lever?
   ***Answers will vary. Ensure that the groups have time to discuss their ideas and to share those ideas with the class.***

## Applying the Idea

- Discuss the results of the experiments with the whole class.
- Ask the students to record the processes they used to balance the system. They should understand that two factors are involved in balancing the lever:
  1. The force of the load and the force of the effort.
  2. The distances the effort and the load are from the fulcrum.

## Extending the Idea

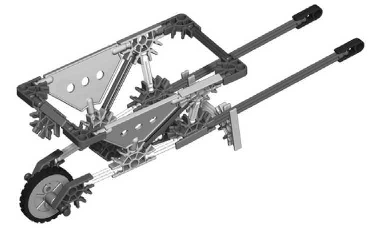
- Suggest that students collect a variety of small items from around the classroom they can balance against a pile of pennies. They will place the items in the load tray and add pennies to the effort tray until the lever is balanced. Students will develop their own data table to keep track of their findings. They need to include the lengths of the effort arms and resistance arms for any of their measurements and they should vary the lengths of the effort arm at least once for each item they test. Students will finish their investigation with a description of what they discovered.

**JOURNAL CHECK:**

- ✔ Explanation of how to balance the balance.
- ✔ Labeled diagram of the balance identifying fulcrum, effort, and load.
- ✔ Completed table with results of their balance experiments.
- ✔ General rule for balancing a lever.
- ✔ "Extending the Idea" investigation.

# THE WHEELBARROW:

## An example of a 2nd Class lever



## OBJECTIVES

**Students will:**

1. Identify the fulcrum, resistance and effort on a wheelbarrow.
2. Determine the lever class of a wheelbarrow.
3. Demonstrate how the wheelbarrow functions as a 2nd Class lever.
4. Modify the wheelbarrow to make lifting a load even easier.

## MATERIALS

### Each group of students will need:

- Building Instructions Booklet and K'NEX parts
- Marker
- Dot stickers or pieces of masking tape
- A large pile of washers, small paper clips or pennies
- A piece of aluminum foil or plastic wrap, approximately 15 x 20 cms. (6 x 8 inches)
- Student Journals

## PROCEDURE

### Introduction

- Review the concept that simple machines help to make work easier. Remind the class that they have already discovered with the balance activity: a 1st Class lever can help lift a heavy load (an adult) with only a small amount of applied effort (a small student), so long as the load is positioned close to the fulcrum. This principle is the basis of all levers – **if a heavy load is positioned close to the fulcrum, less force (effort) is needed to move it.**

- Review with the class where the fulcrum, load and effort are located in a 1st Class lever. Refer to the examples outlined in the Key Concepts.

- Ask the class if they would use a seesaw or a balance to move a heavy load across their backyards. Probe for reasons for their responses.

  ***Students should respond that the seesaw moved a load vertically and not horizontally and would be of no use to them in this situation; the balance, in the form of two equally weighted carriers, could be used, but only if they could first lift it vertically onto their shoulders.***

- Ask what else they could use to move the load across the yard. *(Students may suggest a 4-wheeled cart, a handcart, or a wheelbarrow.)* Explain that they will continue their investigations into levers by building and experimenting with a wheelbarrow. The students may be familiar with a wheelbarrow but not recognize it as a lever in action. Explain that a wheelbarrow is a lever but, because it has a wheel, it not only lifts a heavy load but it can make transporting that load easier - the wheel on the front reduces friction with the ground.

- Ask the following questions:

  (a) What types of loads are generally carried in a wheelbarrow?

  (b) How are wheelbarrows loaded and unloaded?

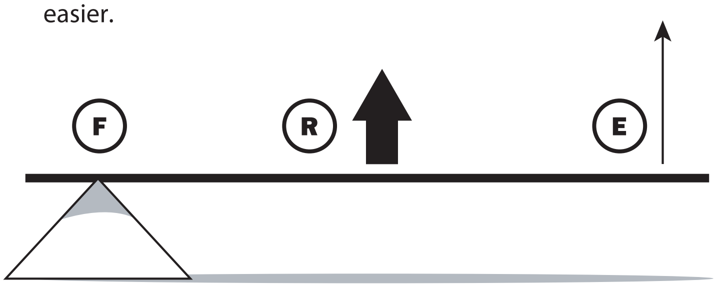
### BUILDING ACTIVITY

- Organize the class into teams of 2 (maximum 3) students.
- Invite the students to build the **WHEELBARROW** model (pages 6-7 of the Building Instructions booklet.) We recommend that one student build steps 1-2 and the other, steps 3-4. The parts should then be assembled, as shown, to form the completed wheelbarrow.

## INQUIRY ACTIVITY: How does a 2nd Class lever make moving a heavy load easier?

- Encourage the students to explore their machine to discover where the fulcrum (pivot point,) load and effort force are located.
- Ask the students to prepare stickers, or tape, to identify and label the parts of the wheelbarrow.

  **F** - Fulcrum  **L** - Load  **E** - Effort
- They should position their labels in the appropriate places.
- Ask the students to which class of lever the wheelbarrow belongs and why. *(They should look at the examples displayed around the classroom for clues.)* On the blackboard draw a diagram to show the positions of the fulcrum, load and effort in a 2nd Class lever. Using the diagram, ask them to think about the characteristic features of a 2nd Class lever. Record their answers on the board. Leave this information on the board for reference.
- Use the following script to help the students inquire into how a 2nd Class lever helps to make moving a heavy load easier.




- ***The resistance is always closer to the fulcrum than the effort.***
- ***Resistance and effort always move in the same direction.***
- ***Work is easier because the effort is applied a long way from the fulcrum. (There is a long effort arm to multiply the force.)***

**Steps**

**1.** (a) Ask one student from each group to collect a large pile of washers, paper clips, or pennies from the teacher's desk. Ask them to carry the pile back to their work area in one hand only.

(b) Was it hard to carry these loose items in your hand? Did any fall out on your way to your desk?

(c) While many of you managed to return to your desks without dropping anything, do you think that would have been possible if you had been provided with a large handful of sand?

***Students should notice that the loose items can easily fall out of their hands as they transport them to their desks. Sand would easily slip through their fingers.***

**2.** (a) Give each group a sheet of aluminum foil or plastic wrap.

(b) Line the tray of the K'NEX wheelbarrow with the aluminum foil or plastic wrap. Fill the tray with the pile of washers, paper clips, or pennies. Then use the wheelbarrow to lift, move, and dump the load. Make sure you dump the load over the front of the wheelbarrow, not the side.

(c) What did you notice about moving the pile of material with the wheelbarrow? What kinds of loads would be easiest to move in a wheelbarrow and why?

***Students should notice that it is easier to move the loose pile in the wheelbarrow because it is collected in one place and all they have to do is lift the handle to move it. The wheelbarrow can be used to move many different loads, but is particularly useful for moving loose, heavy loads like sand or bricks.***

(d) Imagine that you have to provide someone who has never used a wheelbarrow with precise instructions for its use. In your journals, record step-by-step what they need to do.

***Students should include: place objects in the wheelbarrow - apply effort to lift the handles and the supports so that the wheelbarrow pivots on the wheel – this lifts the load at the same time – apply effort to push the wheelbarrow forward – the wheel helps overcome friction as the wheelbarrow travels over the ground - apply more effort to raise the handles higher to dump out the load – lower the handles of the wheelbarrow so the supports rest on the ground.***

**3.** (a) An even heavier load needs to be moved. What changes could be made to your present design to allow it to move this heavier load without increasing the effort needed to lift the handles? Using extra K'NEX pieces, change your wheelbarrow to make it easier to lift the load. (Students may need some help with this; ask them what they know, from their inquiries so far, about making a load easier to move.)

(b) What did you do to your model to make it easier to lift the load?

(c) Why did you choose to do that?

***The wheelbarrow is a 2nd class lever so to make lifting easier, the students should lengthen the wheelbarrow's handles. This will move the effort even further from the fulcrum and make it easier to lift the load.***

## Applying the Idea

- Review with the class the characteristics of a 2nd Class lever:

  (a) Where is the fulcrum located?

  ***At one end of the lever, closer to the load than the effort.***

  (b) Do the effort and resistance (load) move in opposite directions, as is the case with a 1st Class lever?

  ***No. Effort and resistance always move in the same direction. Lift up the lever and the load also moves upwards.***

  (c) What happens when the effort is applied to the lever a long way from the fulcrum?

  ***It multiplies the force and makes work easier.***

- Ask the students to record in their journals the reasons why the wheelbarrow is a 2nd Class lever and how this helps make lifting heavy loads easier. They should include diagrams and sketches.

  *Students should understand that the effort is further from the fulcrum than the load and that* ***the longer the effort arm, the more the effort force is multiplied.*** *This makes it possible to move a large load with a small input of effort.*

- Using K'NEX, invite the students to build another example of a 2nd Class lever. Ask them to explain how the machine works and why it is a 2nd Class lever.

  ***Suggestions for 2nd Class lever model - door, paper cutter, joystick.***

## Extending the Idea

- Using the library and Internet, investigate a **travois** and find out how Native Americans on the Great Plains used this tool to move heavy loads. Explain that not all cultures use the wheel to help move heavy loads.
- Explain how a travois is like a wheelbarrow. You may want to visit this web site for information: http://www.encyclopedia.com/html/t1/travois.asp

  ***Like a wheelbarrow, a travois is a device used to transport a load. It consists of a pair of long poles hitched to a horse or dog. The load is strapped across the poles. The animal pulls the load as it walks while the ends of the poles drag on the ground. The travois is like a wheelbarrow, without the wheel; it is pulled instead of pushed.***

### JOURNAL CHECK:

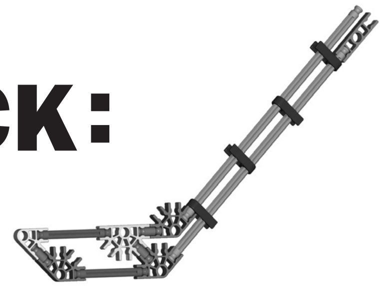
✔ Identification of the wheelbarrow as a 2nd Class lever.

✔ Characteristics of a 2nd Class lever, with diagrams.

✔ Reasons why a 2nd Class lever makes work easier.

# THE HOCKEY STICK:

## An example of a 3rd Class lever



## OBJECTIVES

### Students will:

1. Identify the fulcrum, resistance and effort on a hockey stick.
2. Determine the lever class of a hockey stick.
3. Demonstrate how the hockey stick functions as a 3rd Class lever.
4. Through measurements, demonstrate how a 3rd Class lever can increase distance and speed at the expense of force.

## MATERIALS

### Each group of students will need:

- Building Instructions Booklet and K'NEX parts
- Marker
- Measuring tape
- Dot stickers or pieces of masking tape
- Small Post-It notes
- Student Journals

### You will need:

- Examples of sports equipment such as: ice hockey stick, baseball bat, golf club, tennis racquet, field hockey stick, and lacrosse stick.

(Check with your Physical Education Department.)

## PROCEDURE

### Introduction

- Explain to the students that they have one more Class of lever to investigate: A 3rd Class lever. Ask the students to recall the ways in which the other two classes of levers help to make work easier – changing the direction of a force and increasing a force.
- Explain that to move an object using a 3rd Class lever actually requires more effort than if you were to simply move it without the lever. Ask why we might want to use this kind of lever if it requires a large input of effort.
- Probe for ideas about other things that a lever might be able to do. Help the students discover that we can use levers to not only make moving/lifting objects easier but to move them **further, faster**.
- Ask the class for situations where they might want to move something very quickly over a long distance and where they would be prepared to exert a great deal of effort for a short time to accomplish this goal. (If necessary, provide a hint about sports activities.)
- Explain that a number of pieces of equipment that they use or have seen used at sporting events are 3rd Class levers. People use them because they are prepared to use a lot of effort for a short time to make the ball or puck move far and fast. Ask for some examples of such equipment.
- Have a display of sports equipment available – either the actual items or pictures of them. (Suggestions: ice hockey stick, baseball bat, tennis racquet, golf club, lacrosse stick, field hockey stick.) Encourage the students to create a collage with pictures of 3rd Class levers used as sports equipment.
- Explain that the students will build a hockey stick to investigate the characteristics of a 3rd Class lever.

### BUILDING ACTIVITY

- Organize the class into teams of 2 (maximum 3) students.
- Invite the students to build the **HOCKEY STICK** model (page 8 of the Building Instructions Booklet.)

## INQUIRY ACTIVITY:
## How does a 3rd Class lever help to move a load faster and further?

- The students should explore their machine to discover where the fulcrum (pivot point,) load, and effort force are located. Ask the students to look at the photo on page 8 of the Building Instructions booklet and observe the position of the hockey player's hands. Then use the model stick to hit small balls of paper. (They should take turns doing this.) Remind the students to check that their hands are positioned in the same locations on their stick as those of the player in the photo.
- Ask:
  - (a) Which hand acts as the fulcrum? (Top hand)
  - (b) Which hand provides the effort? (Bottom hand)
  - (c) Where is the load? (The blade of the stick)

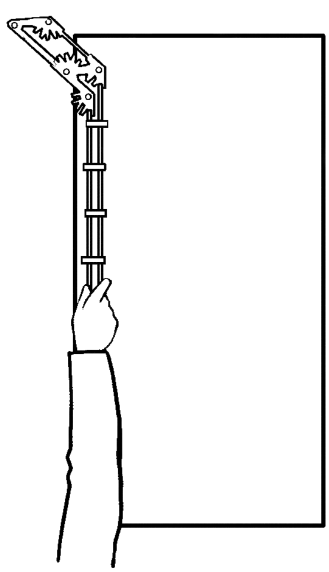
  ***Note:** It may be difficult for students to realize that their wrist is the fulcrum: their wrist provides the point of rotation – just like a door hinge.*
- Ask the students to prepare stickers or tape to identify and label the parts of the hockey stick.

  **F** - Fulcrum **L** - Load **E** - Effort
- Discuss where the stickers should be positioned. Draw a diagram on the blackboard and ask the students to include a sketch of the labeled hockey stick in their journals. The students should also add a sentence to explain how a 3rd Class lever is different from a 2nd Class lever.

  ***The effort is closer to the fulcrum than is the resistance/load.***

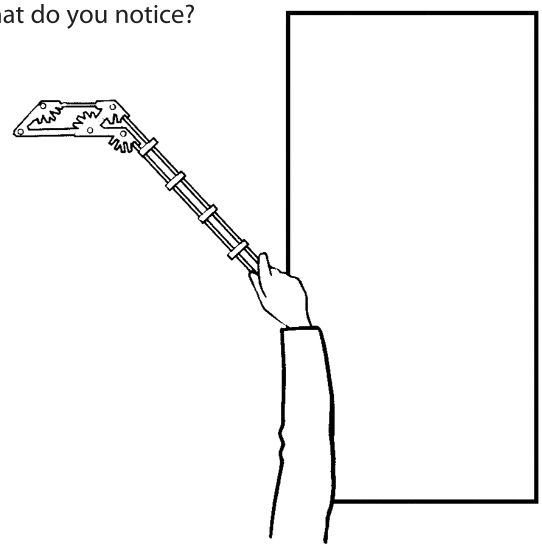
**Steps**

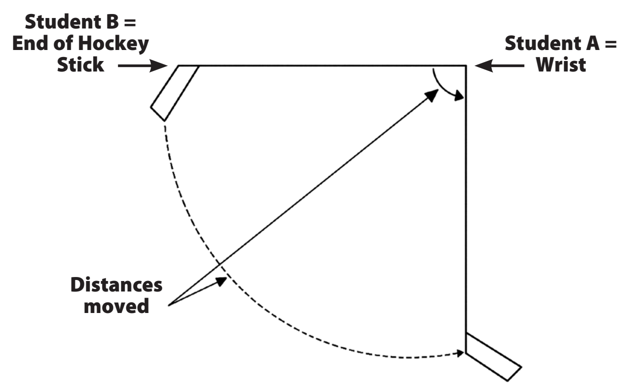
**1.** (a) ***Take turns to do this.*** Use only one hand for this experiment. Hold your hockey stick with the top of the stick in your hand and your fingers on the top purple connector. Lay your arm on your desk so the inside of your arm lines up with the edge of the desk.



(b) Without moving your arm, bend your wrist away from the desk so that the hockey stick also moves away from the edge of the desk. Pay attention to the distance your wrist and the hockey stick move.

(c) What do you notice?






***Students should notice that for a small movement of their wrist, the hockey stick quickly moves through a long distance.***

***NOTE:** Some students may find it difficult to understand why the end of the hockey stick moves further and faster than the wrist - they will think that because they are connected they must move at the same speed.*

***You may want to demonstrate the different speed of movement in the following way. Ask two students to hold onto either end of a long hockey stick or broom handle. They should both face in the same direction. Student A represents the wrist and Student B represents the end of the hockey stick. Ask them to turn through a quarter (1/4) of a circle. The other students should note their starting point. As they turn the student who represents the end of the hockey stick will have to move quickly in order to keep up with the student representing the wrist of the hockey player. That student (B) will also have moved further than the student who is the "wrist".***

2. Distribute measuring tapes and ask the students to repeat the experiment in Step 1 using the following process:
   (a) Hold your hand at the end of the stick with your fingers on the top purple connector. Your fingers are acting as the effort force. Repeat Step 1(b) but this time your partner should measure the distance from the edge of the desk to where you are holding the top purple connector in your hand. Then the distance from the edge of the desk to the yellow connector on the hockey stick should be measured.
   (b) What do you notice? Record your measurements.

      ***Students should notice a significant difference between the two measurements. Depending on the flexibility of their wrists, the distance the end of the hockey stick moved could be four times greater than the distance their wrists moved.***

3. Using both hands, try hitting the ball of paper again with the stick. What do you notice about the distance it travels and speed it moves?

   ***Students should notice that it moves both further and faster than their hands.***

## Applying the Idea

- Ask the students to write in their journals what their measurements suggest about how a hockey stick helps the players in a hockey game.

  ***They should explain that the stick moves much further and faster than their hands. This helps them move the puck quickly across the ice, although because of the position of the effort close to the fulcrum, they must apply a large amount of effort to move even a small load.***

- Explain that the ice hockey player in the photograph on page 8 of the K'NEX Building Instructions booklet needs an improved design for his stick to help him score more goals. He knows that he isn't hitting the puck fast enough but he doesn't know whether he should buy a longer or shorter stick. Your task is to provide evidence, by modifying and testing your hockey stick, which may help him make a decision. Report your findings to the class.

  ***The students should extend the length of the stick. A stationary puck needs a great amount of force applied to move it from a stationary position to high speed in a short time period. A longer stick makes the head of the stick move much faster than the player's hands – the optional experiment on Page 27 using a broom handle or hockey stick rotated through 90 degrees demonstrates this. A disadvantage of the longer stick is that with the load further from the fulcrum it requires more effort to hit it, and it may also be more difficult to control the head movement.***

  ***A shorter stick needs less effort to move the load because it is closer to the fulcrum, provides greater control over the head movement but the hitting head and, therefore, the puck won't move as quickly.***

  ***NOTE: You could also demonstrate this concept by having 1 student use a broom with a long handle and another using a broom with a short handle to sweep over an area.***

## Extending the Idea

1. Using the library and Internet, investigate some of the 3rd Class levers used in sports such as baseball/softball bats, tennis racquets, golf clubs, fishing rods. How do the designs of different types of sporting equipment meet the needs of the players? What do the players need to do to meet the objectives of the game? The following web site, for example, has information on baseball bats: http://exn.ca/stories/2000/10/13/55.asp

2. Students should build a K'NEX model of one of the pieces of sports equipment they have researched. They should explain/show how the lever works and helps to complete the task. The fulcrum, effort and load should be identified.

3. If possible, show video clips of athletes using these types of equipment so that students may observe the 3rd Class levers in action.

### JOURNAL CHECK:

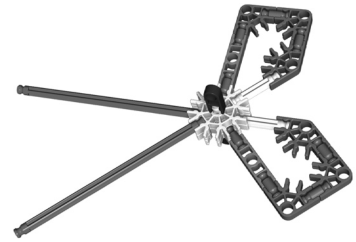
✔ Identification of a hockey stick as a 3rd Class lever.

✔ Labeled diagram of a hockey stick.

✔ Measurements and explanation about how a hockey stick helps the players in a hockey game.

# A PAIR OF SCISSORS:

## An example of connected 1st Class levers



## OBJECTIVES

### Students will:

1. Identify how scissors are 2 connected 1st Class levers.
2. Demonstrate how a pair of scissors work by identifying fulcrum, effort and resistance (load).
3. Investigate other examples of cutting tools that work with a similar action to a pair of scissors and identify how the design fits them for the job for which they are used.

## MATERIALS

### Each group of students will need:

- Building Instructions booklet and K'NEX parts
- Marker
- Dot stickers or pieces of masking tape
- Small rolls of modeling clay
- Student Journals

### You will need:

- A pair of scissors.
- Card; paper; fabric pieces; thread; wire; tree branch.
- Other types of cutting mechanisms. For example: lopping shears; dressing making shears; embroidery scissors; hair cutting scissors; hedge trimmers; tin snips.

**NOTE 1:** Check with the custodian at your school, as he/she, may be able to provide some of these items.

**NOTE 2:** Use these items for demonstration purposes only. Do not give these implements to the students.

## PROCEDURE

### Introduction

- Explain to the class that they have investigated the three classes of levers but some levers that they use everyday are actually double levers.
- Explain that they will investigate a familiar tool - a pair of scissors - to discover how they work and why they are considered to be a simple machine.
- Review with the class the types of materials that scissors (or variations of scissors) can cut: paper, cardboard, fabric, hair, wire, sheet metal, trees branches, or the locks off their lockers. Explain that the size and the shape of the scissors will vary, depending on what they have to cut through.

### BUILDING ACTIVITY

- Organize the class into teams of 2 (maximum 3) students.
- Invite the students to build the **SCISSORS** model (page 9 of the Building Instructions booklet.)

## INQUIRY ACTIVITY:
## How do scissors function as connected 1st Class levers?

**Steps**

**1.** (a) Ask one member of the team to hold the model of the pair of scissors out in front of them so that the blades are in a horizontal position (parallel to the floor.) They should then hold just one of the handles and allow one half of the scissors to swing freely like a seesaw.

***Demonstrate this to the class with either your own model or an actual pair of scissors.***

(b) Ask the class to name a scientific concept that is used to make the scissors work. Provide a clue: they have been examining levers, so is the lever at work in the pair of scissors?

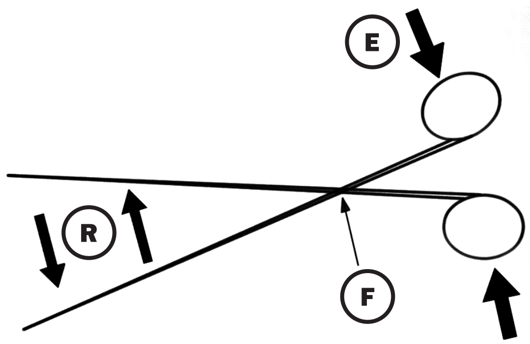
***Yes. The scissors have a hinge or fulcrum about which each blade rotates.***

(c) Ask them to identify where the fulcrum is located, where the effort is applied *(the handles)* and what acts as the load.

***The resistance of the paper or card to the cutting blades.***

(d) If necessary, help the students identify the two levers at work in the pair of scissors.

**2.** (a) Draw a diagram on the blackboard to illustrate that scissors are made from two 1st Class levers.




(b) Draw the students' attention to the arrows on the diagram and ask them what happens to the direction of the effort force in a 1st Class lever.

***Students should respond that the machine reverses it.***

Ask if this is the case with the pair of scissors.

***Yes. Looking carefully at the diagram will help the students to identify the two 1st Class levers making up the pair of scissors.***

(c) They should use stickers or tape to identify and label the parts of the scissors and make a drawing in their journals.

**F** - Fulcrum **L** - Load **E** - Effort

**3.** Demonstrate cutting through a piece of paper - emphasize that the two blades work by cutting across each other in a shearing action.

**Note for the teacher:** The sharpened edges of the blades are actually wedges that work in opposite directions to each other.

Use the following script to direct the students' inquiry into how scissors work and why they are an example of two connected levers.

**4.** (a) Put a piece of modeling clay (approximately 10 cms. x 3 cms.) lengthwise between the blades of your scissors and squeeze as if you were cutting through paper.

(b) What do you notice about the depth of the indentation made by the blades?

- Where was the indentation deepest?
- What does this tell you about the cutting action of the scissors?

***Students should notice that the indentation in the clay is deepest closest to the fulcrum. From this observation they should understand that the cutting power of the scissors is greatest nearest the fulcrum and decreases as you move further away.***

(c) When would you want to cut near the fulcrum? When would you want to cut near the blade tips?

***They should understand that they would want to cut near the fulcrum when cutting something thick and cut near the tips when making smaller cuts or cutting thin materials.***

(d) Record your findings in your journal.

**5.** Using what you know about 1st Class levers, why is there a difference in cutting power along the blades of the scissors?

***The students should state that when the resistance is close to the fulcrum less effort force is needed to move it, while further away you need to apply more effort to move the same load. Cutting near the fulcrum is easier than cutting near the blade tips. If required, draw a diagram on the board to reinforce the concept.***

**6.** (a) Show the students a selection of other cutting tools that have a similar cutting action to scissors. (Examples: lopping shears; dressing making shears; embroidery scissors; hair cutting scissors; hedge trimmers; tin snips.)

(b) Discuss how all the cutting tools are based on the same basic design, but that the design has been modified to meet a particular need.

(c) Ask the following questions about each example:

- What a type of material is this designed to cut?
- Would scissors be able to cut these materials? If not, why not?
- How does the design of the different cutting tools allow them to cut materials that scissors cannot?

***Where possible, attempt to cut the materials the students suggest with the tool under discussion. This will demonstrate its effectiveness, or otherwise.***

***Students should see that cutting tools with short blades and long handles are used to cut materials like wire or thick branches – these are difficult things to cut through and require a great amount of effort. The handles are long to increase the squeezing force (effort) while the short blades mean that the load is near the fulcrum (hinge) where the cutting forces are greatest. By comparison, scissors for hair cutting tend to have long blades and short handles because the main need to is to make long straight cuts – only a small cutting force is needed to cut through hair.***

## Applying The Idea

- Explain in your journals (i) why scissors are considered to be connected (or double) levers and (ii) how they work. Include a labeled drawing to illustrate your explanation.
- Make labeled drawings of different cutting tools indicating the position of the fulcrum, effort and load. Add notes to describe how the design of the cutting tools fit them for the jobs for which they are used.
- Modify your K'NEX scissors model design so that it has a much stronger cutting or gripping action. Test the revised model on the modeling clay. Make labeled drawings of the new design and write a description of how the design works and how the modifications have made the cutting action stronger.

## Extending The Idea

Investigate other connected levers and build them using K'NEX. Explain how double levers help do work based on their class. For example, a nutcracker is a 2nd Class connected lever. A large amount of force is required to break the nut's hard shell. So much so, it's almost impossible to do it by hand. It is best to use a 2nd Class connected lever to ensure that the machine, rather than your hand, increases the applied effort.

**JOURNAL CHECK:**

✔ Explanation of where scissors have the most cutting power.

✔ Explanation, with labeled diagram, of how scissors are an example of a double 1st Class lever.

✔ Description of how the shape of the scissors affects the job it can perform.

✔ Explanation of how the design of other types of cutting tools fit them for their jobs.

## Concluding Activities for the Unit on Levers

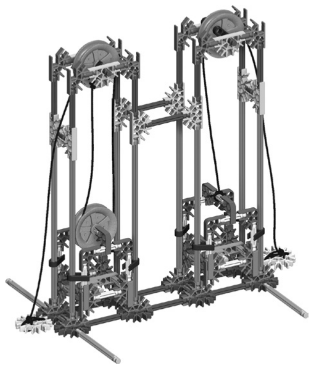
Suggest that students search the Internet for additional information about levers. Recommend that they enter the key words: *Simple Machines* into a search engine such as Google or visit http://www.professorbeaker.com and search for 'lever'.

Working in pairs, students should look carefully at the examples of levers present in the classroom, (or at pictures displayed around the classroom,) and then group the levers based upon where they think the fulcrum, effort, and resistance are located. They should consider precisely where they would exert a force on the machine and where the machine exerts a force on something else. Their ideas should be recorded in their journals.

Ask the class to think of ways in which our lives would be different without the use of this simple machine. Encourage them to consider the ways in which levers make our work easier every day.

## Building Challenge

Your class has been invited to a local orchard for apple picking. The orchard, however, does not have enough ladders for everyone to use. Your challenge is to design a tool that can be used by someone standing on the ground to remove apples without bruising them or having them hit anyone. Using K'NEX and other materials, design and build a lever that will help remove and collect the apples from the trees. Explain how your tool is a lever and how it solves the problem.



# PULLEYS

## Background Information

## OBJECTIVES

### Students will:

1. Study the characteristics of pulleys to understand how they work.
2. Discover the relationships between the parts of a pulley system.
3. Investigate the relationships between force, distance, direction, and work in a pulley system.
4. Construct combination pulley systems and use it to lift a load.
5. Demonstrate how different types of pulleys function and where they are used.
6. Analyze objects/tools in terms of their application as pulleys.

## KEY TERMS and DEFINITIONS for the teacher

The following is intended as a resource for the teacher. The age of the students, their abilities, their prior knowledge, and your curriculum requirements will determine which of these terms and definitions are appropriate for you to introduce into your classroom activities. These terms are not presented as a list for students to copy and memorize. Rather, they should be used to formalize and clarify the operational definitions your students develop during their investigations.

**Pulley:**
A wheel, with a groove in its outside rim, that spins freely on an axle; a rope, cable or chain runs in the wheel's groove and may be attached to a load.

**Fixed Pulley:**
A pulley attached to a solid surface; it does not move when the rope is pulled, other than to turn in place. Fixed pulleys change the direction of an applied force.

**Moveable Pulley:**
A pulley attached directly to the load being lifted; it moves when the rope is pulled.

**Combination Pulley:**
A series of fixed and moveable pulleys used together to gain the advantages of both in doing the work.

**Block and Tackle:**
A specific combination of pulleys used to lift very heavy objects: the block is the frame holding the pulleys; the tackle is the rope or cable.

**Work:**
The task being completed while using the pulley. In science, work refers to the use of force to move a load (object) through a distance. It can be defined as follows:

$$W = F \times d$$

Where **W** = work
**F** = the force (effort) applied to the task
**d** = the distance through which the force is applied

**NOTE:** If the object has not moved, work has not been done.

**Force:**
Any kind of push or pull applied to an object.

**Effort:**
The force that is applied to move one component of a simple machine (i.e.: the force that is applied to do work.) The force applied to a simple machine is called the *effort force.* With a pulley it is the force that is applied to the pulley by pulling on the rope to lift a load or overcome resistance.

**Load:**
The object (weight) moved or resistance that is overcome with a pulley. It exerts a force (resistance) against the pulley.

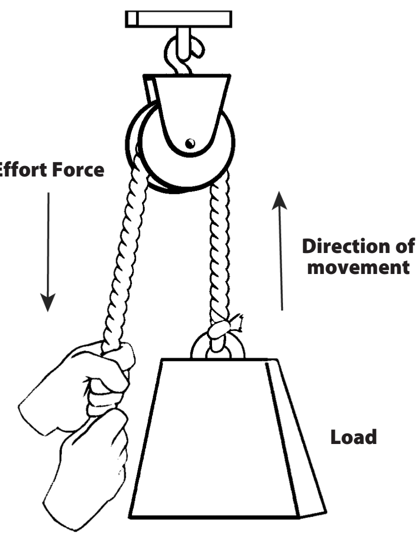
**Friction:**
The force caused when 2 surfaces rub together as an object moves.

**Mechanical Advantage (MA):**
A mathematical calculation that indicates how many times a simple machine multiplies the effort force. For a pulley, it can be found by counting the number of cords/ropes that support each moveable pulley. For example, if you are using 3 moveable pulleys which are supported by six cords, the Mechanical Advantage (MA) = 6.

Mechanical Advantage is always expressed as a number without a unit. (See above example.)

## KEY CONCEPTS

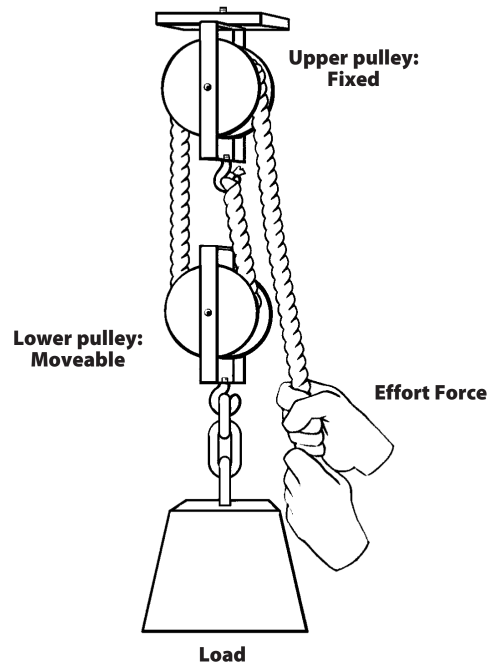
- A pulley is a simple type of mechanism; it has been used for thousands of years to help make the job of lifting heavy objects easier.
- Combinations of pulleys can transfer movement and force from one to another via ropes, chains, belts, or bands.
- Pulleys makes work easier in the following ways:
  1. A pulley can **change the direction** of an applied effort force.
     (a) A downward pull on the rope running over the fixed pulley will result in an upward movement of the load. (See diagram below.) The force is applied in the direction that gravity acts – downwards. This is easier than pulling up against gravity. It also allows you to add your body weight to the effort made by your arm muscles, making it appear easier to lift the load.




     (b) In addition to changing the direction of the applied effort force in a vertical direction, pulleys can also be used to move loads horizontally. For example, they can be used to open and close curtains/drapes or to move a clothesline.

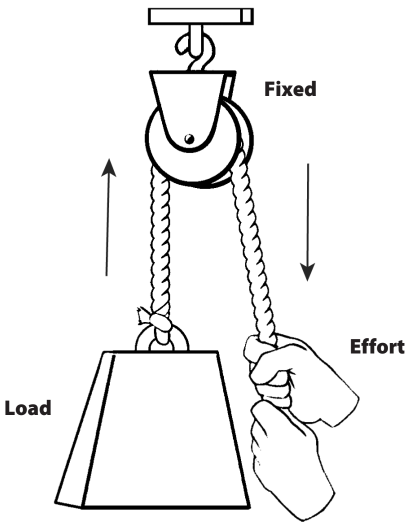
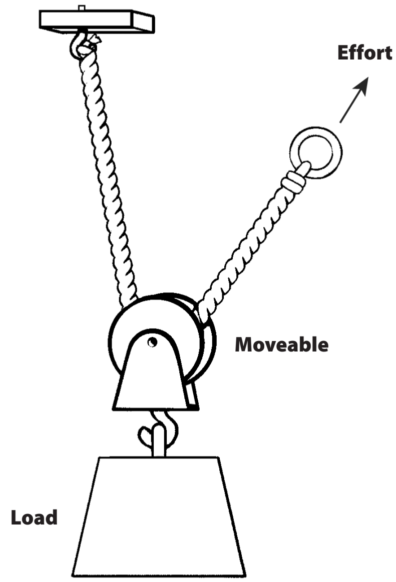
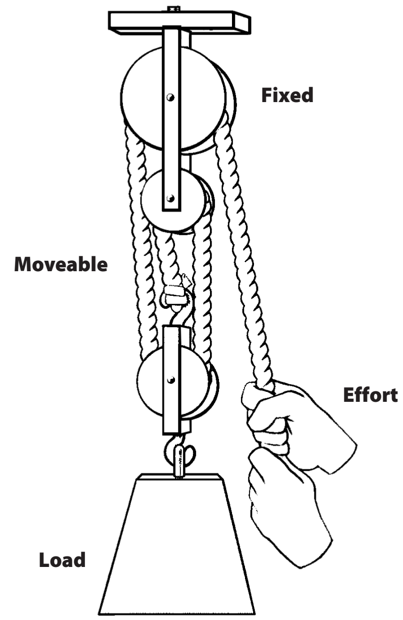
  2. Pulleys can **multiply the applied effort force.** As more pulleys are used in the system, less effort is required to raise the load, but you must pull more rope through the system. In other words, you pull a longer length of rope but you don't have to pull as hard as you would if you used only 1 pulley.

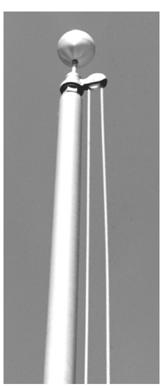
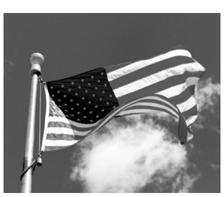
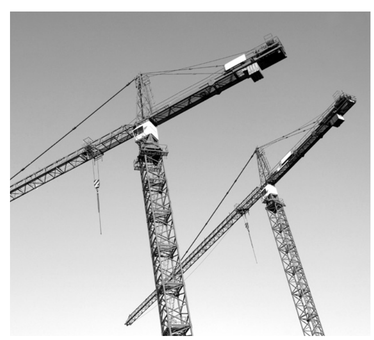
     (Remember **W = F x d**. In other words, work over a longer distance and the force is increased.)

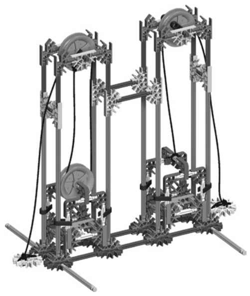



For example, with a system composed of 2 pulleys - one fixed and the other moveable – you need to apply only **half** the effort force that would otherwise be needed to raise the load without the help of the pulleys, but you must pull **twice** the amount of rope. This is because the moveable pulley is supported by two sections of rope and you must move both sides of the rope to lift the load.

# PULLEY SUMMARY

| FIXED PULLEYS | MOVEABLE PULLEYS | COMBINATION PULLEYS |
|---|---|---|
|  |  |  |
| Fixed to a supporting structure. Not directly attached to the load. | Attached directly to the load being lifted. | Two or more sets of pulleys connected by the same rope. The upper set comprises fixed pulleys attached to a supporting structure; the lower set(s) is moveable. |
| Do not move when the rope is pulled, other than to rotate in place. | Move when the rope is pulled. When the pulley moves, so does the load. | Upper set does not move; lower set(s) moves when the rope is pulled. |
| Effort is always applied by pulling down. This is easier because effort is applied in the same direction as the force of gravity. | With one moveable pulley, the effort force is applied by pulling upwards. | Effort is applied by pulling down. |
| Change the direction of the applied effort force. A downward pull on the rope results in an upward movement of the load. | Multiply the force applied to the load. | Change the direction of the applied force **and** multiply the force applied to the load. |

| FIXED PULLEYS | MOVEABLE PULLEYS | COMBINATION PULLEYS |
|---|---|---|
| The load moves the same distance that the rope is pulled by the effort. | With one moveable pulley, the load will move half the distance that the rope is pulled by the effort. | The distance the load moves in comparison to the applied effort force will depend on the number of pulleys. It can be determined from the number of rope segments supporting the load. EG: with 4 rope segments, the load will move one quarter (1/4) the distance of the effort. |
| Lifting with a fixed pulley, in theory, takes the same amount of force as lifting without the pulley. In practice, the effort must be greater than the load in order to overcome friction. | Lifting with a moveable pulley requires less force than lifting without the pulley but it must be applied over a longer distance. (Friction does apply.) | As more pulleys are used, less and less effort is needed to lift heavy loads. (Friction does apply.) |
| The load is supported with only 1 rope; Mechanical Advantage = 1. | One moveable pulley supports the load with 2 ropes; Mechanical Advantage = 2. | The number of rope segments that support the load determines Mechanical Advantage. In the example, Mechanical Advantage = 4. |
| **Examples:** flagpole; clothesline; window blind/shade.   | **Examples:** sailboat/yacht; older double-hung window; garage door opening mechanism.  | **Examples:** block and tackle; crane.  |



# THE ELEVATOR:

## An example of a pulley simple machine

## OBJECTIVES

**Students will:**

1. Identify and diagram the various parts of the elevator model.
2. Describe the transfer of energy in the elevator systems.
3. Investigate, demonstrate, and explain how an elevator with a fixed pulley system and an elevator with a moveable pulley system make work easier.
4. Find the mechanical advantage of two elevator systems by "counting support strings."
5. Calculate the mechanical advantage of both elevator systems experimentally.

## MATERIALS

**Each group of students will need:**

– Building Instructions Booklet and K'NEX parts
– Student Journals
– Pennies minted after 1982 (several hundred for the class)
– Gram masses (optional)
– Meter Sticks or Tapes
– String
– Masking tape
– Small cups (3oz. bathroom size) for the Optional Extension Activity

## PROCEDURE

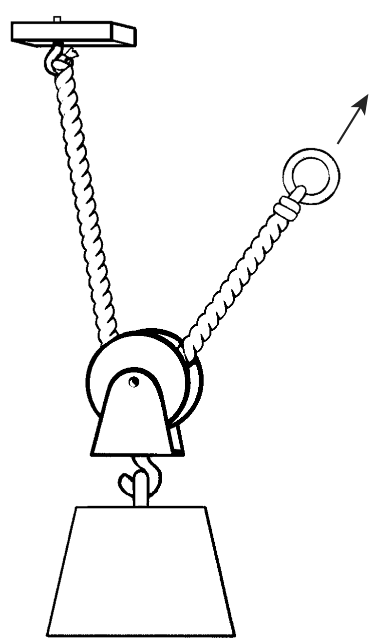
### Introduction

- Briefly discuss pulleys and pulley systems with the class. Ask groups to prepare a list of as many items as they can that use pulleys. Compile a list of their ideas on the board.
- Ask students if any of the pulleys on the list change the direction of force. Have them discuss with their group before responding. If they indicate that a listed pulley system changes the direction of force, ask them to explain their answer.

  ***Possible responses: Pulleys on a sailboat – You pull down and the sails go up; pulley on a flag pole – You pull down and the flag goes up; pulleys on a clothesline – You pull towards you and the clothes move away towards the other clothes pole; etc.***

- Ask students if all pulley systems change the direction of force. Have them discuss with their group before responding.

  ***Not all pulley systems change the direction of force but it is not likely that students have seen such a system. An example of a moveable pulley system that does not change the direction of force is shown here. As the rope is pulled up, the load also moves upward.***



- Ask students if pulley systems multiply force. Have them discuss with their group before responding. Moveable, combination, and block and tackle pulley systems multiply force. Fixed pulley systems do not multiply force.

  ***(Students should be able to cite examples: pulley systems on a sailboat to lift a heavy sail; pulley systems at a garage used to lift heavy engines from cars, etc.)***

- Inform students that they are going to build, investigate and compare two elevators that contain pulley systems.

## BUILDING ACTIVITY

- Distribute the Building Instructions Booklets and instruct each group of 2 – 3 students to collect the K'NEX pieces to build the **ELEVATOR** model (pages 10-15).
- The Elevator model will require that students pay particular attention to detail as they build. Monitor their progress as they work and provide assistance as needed when students place their elevator cars in the framework and string the pulleys.

## INQUIRY ACTIVITY:
## How do these machines change the direction of the effort force?

**Steps:**

**1.** When the models are complete, allow the groups to explore and investigate. Remind students to maintain careful records of the observations in their journals. Point out the fact that the model is actually two different elevators that are supported in the same framework. Ensure that all of the elevators are operating smoothly. Ask students to identify which types of pulley systems they find in this model.

***One elevator with a fixed pulley system and one elevator with a moveable pulley system.***

**2.** Instruct students to draw and label two diagrams of the model in their journals. They will essentially diagram the fixed pulley section on one side of the page and the moveable pulley section on the other side of the page. Ensure the following are identified on the diagrams: effort force, pulley, and elevator car (load). Ask students to include arrows to show the direction of motion for each of the parts above.

**3.** Help the students understand how their model works by asking them to investigate the following questions.

- Where is the effort force applied?

  ***The effort force is applied to the end of the pulley string for both of the elevator systems.***

- What direction must the string be pulled in order to raise the elevator car?

  ***The string must be pulled downward.***

- What type of motion does each moving part of the system produce as the effort force is applied?

  ***The fixed pulley system: the effort force applied in a straight line (linear motion) causes the pulley to turn (rotational motion) and the elevator car to rise (linear motion). The moveable pulley system: the linear effort force causes both pulleys to turn rotate and the elevator car to rise in a straight line.***

- Based on what you have discovered, do both elevators change the direction of force?

  ***Yes! In both cases, when you pull down on the string, the elevator cars rise.***

- What is the function the string provides in the elevator systems?

  ***The string transfers the applied force from the pulley(s) to the elevator cars.***

- What difference do you notice as you operate the two elevators on the model?

  ***You have to pull a lot more string to lift the elevator car attached to the moveable pulley system.***

## Applying the Idea

- Students will count support strings on each of the elevator models to determine how many times the system should multiply force. The students will first verify whether or not the systems multiply force. Instruct students to keep careful records of their work in their journals.

- Provide each group with a stack of pennies (40 is a good number) (gram masses can also be used).

  ***Pennies should be stacked and wrapped in coin wrappers or rolled in paper and taped closed. These rolls of coins can then be laid on the floor of the elevator car. If gram masses are to be used, they can be laid directly on the floor of the elevator car.***

- Instruct students to lift the pennies (masses) several times to gain a sense of how much they weigh. Ask students to place the pennies in the fixed elevator car and pull the string attached to that car several times to lift the elevator car. Ask students if they think they used about the same force to lift the pennies with their hand as they did with the elevator.

  ***They should find that they use about the same force with the elevator and their hand.***

- Ask students to repeat the activity above using the moveable pulley elevator. Are their results the same or different using the moveable pulley system.

  ***The results are different. It requires much less force to lift the pennies with the moveable pulley system.***

- Inform students that one way to determine how many times a pulley system will multiply force is to count the number of sections of pulley string that support the load.

- Have students refer to the fixed pulley system. Ask them how many sections of pulley string go from the pulley to the load.

  ***The students should readily note that there is only one section of the pulley string that extends from the pulley to support the load (elevator car).***

- Tell students that the number of pulley strings that support the load is actually the mechanical advantage of the pulley system. What is the mechanical advantage of the fixed pulley elevator?

  ***It is one! There is only one pulley string supporting the load.***

- Instruct students to count the support strings on the moveable pulley elevator car.

  ***Students should identify two sections of pulley string extending from the pulley to the elevator car.***

- What is the mechanical advantage of the moveable pulley elevator?

  ***Two!***

## Extending the Idea

- Inform students that they are going to complete two investigations to find the mechanical advantage (MA) of the elevator systems. One way to find the mechanical advantage of the pulley systems is to compare the height the elevator car is lifted to the distance the input force is applied (the distance you pull the string to lift the car to the top). Use the following formula to find the mechanical advantage:

$$\frac{\textbf{Distance the pull string travels}}{\textbf{Distance the car rises}} = \textbf{MA}$$

- Ask students to make and record the following measurements:
  - How far does the elevator car move when it is pulled to the top of the framework?

    ***Answers may vary.***
  - How far do you have to pull the string on the fixed pulley elevator to raise the car to the top?

    ***Answers may vary but they should match the answer above.***
  - How far do you have to pull the string on the moveable pulley elevator to raise the car to the top?

    ***Answers may vary but they should be nearly twice as long as the answer for the fixed pulley elevator.***

- Instruct the students to use the formula to find the mechanical advantage of each system.

  ***The MA of the fixed pulley elevator should be approximately one (1). The MA of the moveable pulley elevator should be approximately two (2). The MA of the moveable pulley elevator may be slightly less than two as the added pulley to the system does not allow the elevator to rise all the way to the top of the framework. You can discuss this with the students to see if they can come up with a solution. One idea would be to measure the height of the moveable pulley on the elevator car, double it and add it to the distance the pull string traveled for the moveable pulley elevator.***

**OPTIONAL EXTENSION:**

- Challenge students to design a way to tie small cups to the end of the pull string on the elevators to see if they can measure how many pennies it takes to lift the moveable pulley car and fixed pulley car when the cars carry a load of 20 pennies. Ask them to explain how their answers are related to the MA of the two elevators.

  ***Students can attach cups to the ends of the strings and have one member of the group move the framework to the edge of the table so the cup hangs over the side. As pennies are added, the car will eventually rise. They should note that the moveable pulley car will rise to the top with fewer pennies as the system multiplies force. They will note also that the string on the moveable pulley car will move twice the distance of the other car. That is their clue to the MA.***

### JOURNAL CHECK:

✔ Diagram of the two elevator systems with labels and directional arrows.

✔ Record of student observations and answers to questions.

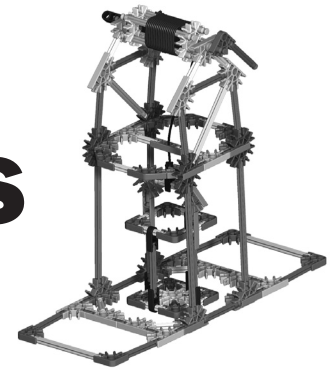
✔ The mechanical advantage of each elevator found by counting strings.

✔ The mechanical advantage of each elevator as found by investigation.

✔ Notes and analyses related to mechanical advantage.

# WHEELS & AXLES

## Background Information



## OBJECTIVES

### Students will:

1. Study the characteristics of the wheel and axle system to understand how it works.
2. Discover the relationships between the parts of a wheel and axle system.
3. Construct different types of wheel and axle systems and demonstrate how they function.
4. Identify whether the wheel turns the axle, or whether the axle turns the wheel, and determine how this affects the way the system works.
5. Identify how the use of a wheel and axle system affects work in relation to force, distance, speed and direction.
6. Understand how the size of the wheel and axle affects the work performed.
7. Analyze objects/tools in terms of their application as wheel and axle systems.

## KEY TERMS and DEFINITIONS for the teacher

The following is intended as a glossary for the teacher. The age of the students, their abilities, their prior knowledge, and the curriculum requirements will determine which of these terms and definitions you introduce into your classroom activities.

**Simple Machines:**
A simple tool that makes work easier to do. Most simple machines have only one moving part. Simple machines make work easier by changing the *way* in which the work is done. They do not change the *amount* of work that is needed to do the job.

**Wheel and Axle:**
A round disk (wheel) with a rod (axle) rigidly attached through its center so that when one turns, so does the other. It is used to transfer force. Some examples actually look like a wheel with an axle, but others have a wheel that resembles a handle, such as that on a fishing reel, or a knob, such as a doorknob or the volume knob on a radio. All wheel and axle mechanisms behave like a lever rotating around a fixed point.

**Force:**
Any kind of push or pull applied to an object.

**Combination Pulley:**
A series of fixed and moveable pulleys used together to gain the advantages of both in doing the work.

**Work:**
The task being completed while using a wheel and axle.

In science, work refers to the use of force to move a load (object) through a distance. It can be defined as follows:

$$W = F \times d$$

Where **W** = work
**F** = the force (effort) applied to the task
**d** = the distance through which the force is applied

**NOTE:** If the object has not moved, work has not been done.

**Effort:**
The force that is applied to move one component of a simple machine (ie: the force that is applied to do work). The force applied to a simple machine is called the effort force. If a wheel is turning an axle, the *effort force* is a measure of the force that is applied to the wheel over the distance that the wheel moves. The machine then transfers the force to the axle, which moves the load.

**Resistance:**
The force exerted by the object (load) upon which one is trying to do work; it works against the effort.

**Load:**
The object (weight) moved or the resistance that is overcome when using a wheel and axle. It exerts a force (resistance) against the wheel and axle.

**Friction:**
The force caused when 2 surfaces rub together as an object moves.

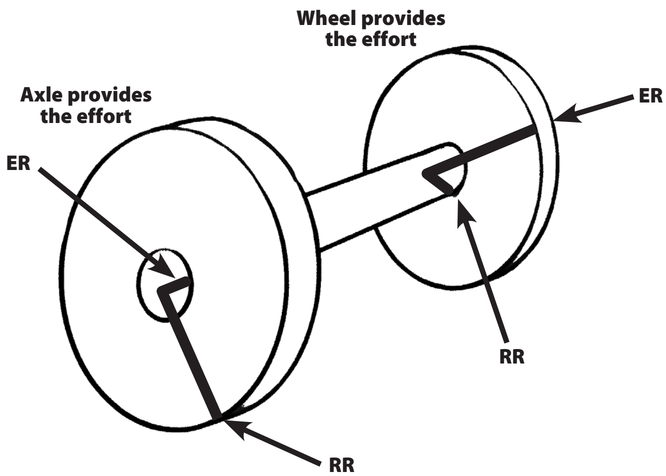
**Mechanical Advantage (MA):**
A mathematical calculation that indicates how many times the simple machine multiplies the effort force. For a wheel and axle system it can be calculated using the following formula:

$$\frac{\text{Effort radius (ER)}}{\text{Resistance radius (RR)}} = \text{MA}$$

Where **ER** = the radius of the wheel or axle supplying effort

**RR** = the radius of the wheel or axle not supplying effort

Mechanical Advantage is always expressed as a number without a unit. EG: MA = 2




## KEY CONCEPTS

- To move a load using a wheel and axle mechanism, the effort force is applied EITHER to turn the wheel OR to turn the axle.

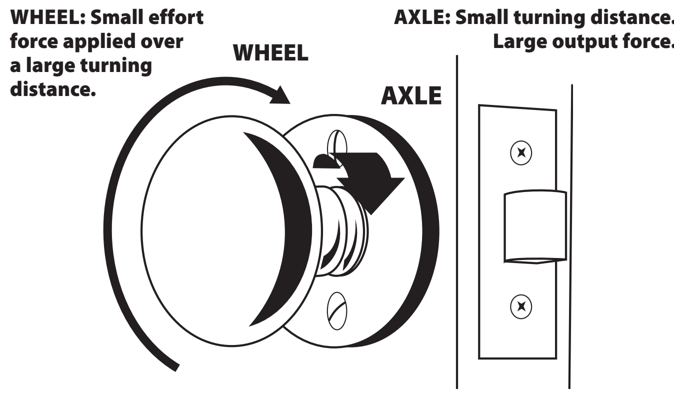
- A wheel and axle mechanism behaves as if it is a rotating lever with the center of the axle as the fulcrum and the wheel rim as the outer edge of the lever. With levers, the further the effort is from the fulcrum, the less effort is needed to move a load. The same is true for the wheel and axle. The larger wheel requires less effort to move a load when compared to a smaller wheel like the axle.

- A wheel and axle system makes work easier by making things easier to move. It can do this in the following ways:

**Multiplying the *force* that is applied to do a job.**

- Because the wheel and axle act like a rotating lever, when the wheel turns, its rim will move a greater distance than the axle, but it needs less effort to turn it. The axle, meanwhile, turning through a small distance, **gains in force** what is lost in the distance moved. The force is increased due to the difference in size between the wheel and the axle.

For example, turning a lock mechanism without a doorknob is very difficult. The doorknob makes this task easier by reducing the effort needed to turn the lock mechanism. The doorknob rotates through a greater distance than the lock spindle but it needs little effort to turn it. At the same time, the lock spindle (axle), moving through a smaller distance, exerts a greater force.



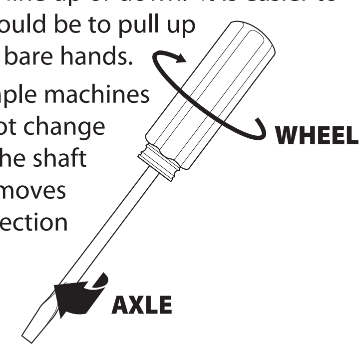

**Multiplying the *distance* over which the job is done.**

- Turning the axle causes the wheel to turn through a greater distance. For example, in a paddlewheel boat, for each full turn, the axle turns in a small circle, while the wheel turns in a big circle. The axle turns only a short distance, but it needs a large force to turn it through that distance. Turning the axle, therefore, is hard but you don't have to turn it far. The edge or rim of the wheel, however turns with less force, but it travels a greater distance and at a faster speed than the axle.

**Changing the *direction* of a force.**

- If you turn the handle on the wishing well, your hand moves in a vertical circle. The bucket, on the other hand, moves in a straight line up or down. It is easier to turn the handle than it would be to pull up the bucket with just your bare hands.

Other wheel and axle simple machines like the screwdriver do not change the direction of a force. The shaft (axle) of the screwdriver moves the screw in the same direction that you turn the handle (wheel) of the screwdriver.



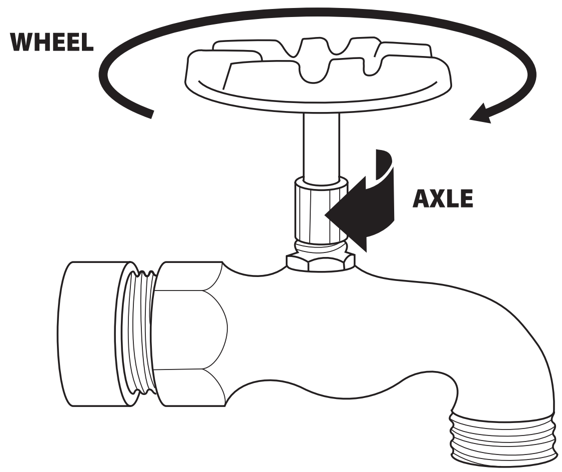

**NOTE:** Some of the wheel and axle systems used on vehicles are different from other wheel and axle simple machines. These have wheels that are NOT fixed to their axles and the wheels simply make moving across a surface easier by reducing the **friction**. These wheels and axles on a vehicle do not offer a Mechanical Advantage.

- As previously noted, simple machines make work easier. They do this by either multiplying the force applied or increasing the distance (rate) the resistance moves. This is because force and distance cannot both increase at the same time. When one increases, the other must decrease since work output is never greater than work input.

## ADDITIONAL EVERYDAY EXAMPLES OF WHEELS and AXLES

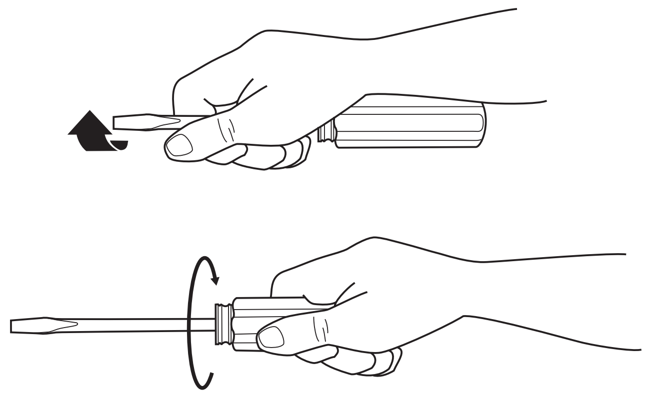
**FAUCET:**

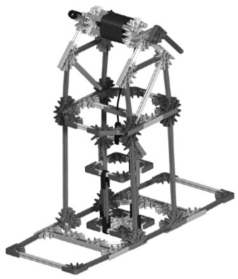
- The handle of the faucet is the wheel. When the handle is turned, using a small effort force, it rotates through a large circular distance. The axle, with its smaller circumference, rotates through a smaller distance with greater force. This then operates the valve in the faucet to allow the water to flow.




**SCREWDRIVER:**

- The handle of the screwdriver is the wheel; the shaft is the axle. The screwdriver's thicker handle and thinner metal shaft rotate together to turn a screw. When effort force is applied to the handle (wheel) of the screwdriver it rotates through a greater distance than the shaft (axle) but this force is multiplied as the shaft rotates through its smaller turning circle and allows the screw to be easily inserted. Turning a large wheel is easier than turning a small axle so the work is made easier. This concept can be demonstrated by attempting to unscrew a screw by turning the metal shaft (axle) of the screwdriver. It will be much harder to do the job this way, compared to turning the screwdriver by its larger handle (wheel).





# THE WELL:

## An example of a wheel turning an axle

## OBJECTIVES

### Students will:

1. Understand the scientific concept of work and the idea that simple machines can make work easier.
2. Demonstrate the characteristics of a wheel and axle.
3. Investigate how a wheel turning an axle makes work easier.
4. Explore how varying the size of the wheel will affect the amount of effort needed to do a job.

## MATERIALS

### Each group of students will need:

– Building Instructions Booklet and K'NEX parts
– Marker
– Paper cup
– Pennies or small paper clips
– Yardstick (Meterstick)
– Student Journals
– 200 gram or 5 Newton spring scale (optional)

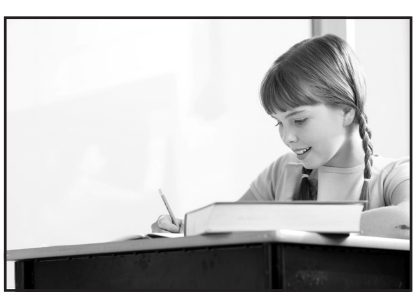
### You will need:

– Pictures and examples of different kinds of wheels and axles. (Suggestions: plastic thread spool with a pencil inserted into its center hole; doorknob; screwdriver.)

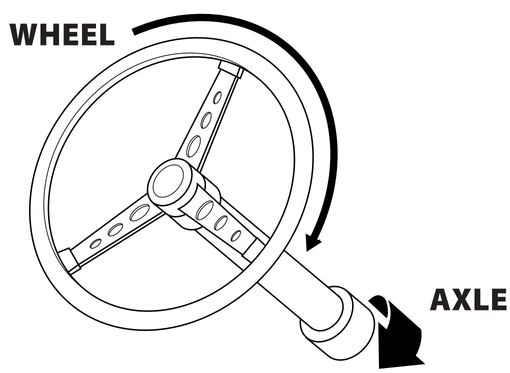
## PROCEDURE

### Introduction

- If this is their first introduction to simple machines you may want to demonstrate the concept of work by having 3 or 4 students pushing as hard as they can against a wall in the classroom for 1 minute. Then ask another group of 3 or 4 students to each push a book across his or her desk. Ask the rest of the class to decide who was doing "work."
- Following this, provide the students with background information on the concepts of work, force, effort, resistance, and load (See Key Terms and Key Concepts on pages 39-41 of this Guide.) Ask them to then identify where the effort force came from and what represented the load or resistance for both activities.
- Ask them if the wall or the books moved. Explain that although the group pushing against the wall exerted a great deal of energy or force, the wall itself didn't move so, from a scientific point of view, no work was done. The group pushing the books, however, did do work. Students should record their observations in their journals.



- Begin the lesson by defining a wheel and axle. (A definition is provided on page 39 of this Guide.) Refer to the fact that a wheel and axle is a simple machine. Have an example available, constructed from a thread spool and pencil, to demonstrate the parts. Draw a labeled diagram on the board. (See diagram below)



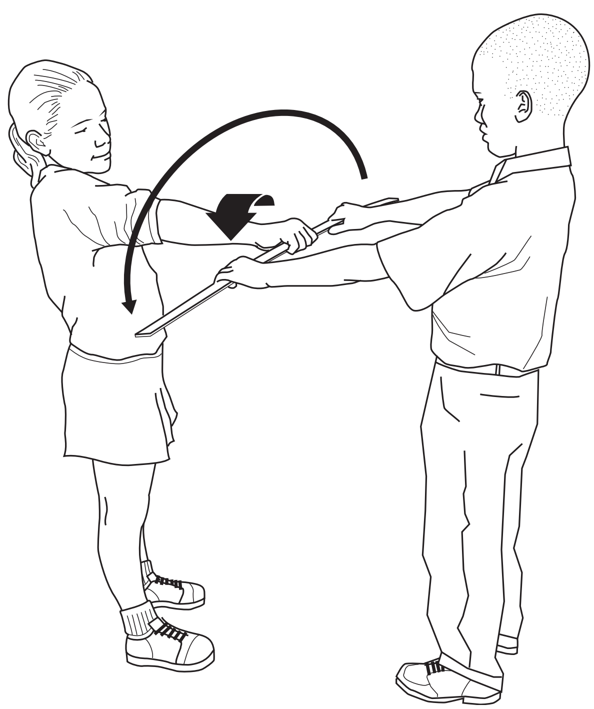

- Ask the students to provide examples of the use of wheels and axles in their daily lives. They will probably describe the wheels and axles on a car or bus. This will give you the opportunity to explain how these differ from other wheel and axle simple machines, in that the wheel moves independently from the axle and the function of the wheel, in this case, is simply to reduce friction. Probe for the less obvious examples, such as faucets, doorknobs and screwdrivers.

- Ask the group to think of ways in which our lives would be different without the use of this simple machine. Encourage them to consider the ways in which wheels and axles make our work easier every day. Ask them to suggest alternatives to doorknobs and screwdrivers. Suggest that they explore these options at home.
- Suggest that they search the Internet for additional information about wheels and axles. (Recommend that they enter the key words: Simple Machines into a search engine such as Google.)
- Organize the class into teams of 2-4 students and distribute yardsticks.

## INQUIRY ACTIVITY

*We would like to thank Susan Frazier and the directors of the SMILE program at the Illinois Institute of Technology for granting us their permission to include the following activity. ©1990. [Please visit http://www.iit.edu/~smile/ph9005.html for further information.]*

- Explain that each team will first explore the characteristics of a wheel and axle by simulating one using their arms and a yardstick.
- Ask one member of each team (A) to grasp the yardstick in the middle and hold it out in front of them. Student B then places a hand on either side of Student A's hand and tries to turn the stick while Student A attempts to prevent it turning. Student B should repeatedly move his/her hands further apart until the stick turns easily.



- Ask the students what they think Student A's hand represented *(axle)* and what the yardstick represented *(wheel.)*
- Ask them to record the experiment in their journals together with a labeled diagram.

## BUILDING ACTIVITY

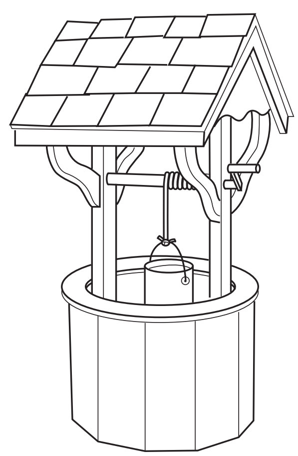
- Explain that they will build a model of a well that incorporates a wheel and axle system. They will then use the model to investigate how a wheel and axle can help them do work.
- Invite the students to build the **WELL** model (pages 16-17 of the Building Instructions Booklet.) The parts should then be assembled, as shown, to form the completed well.

## IINQUIRY ACTIVITY:
## How does the wheel and axle help you do work?

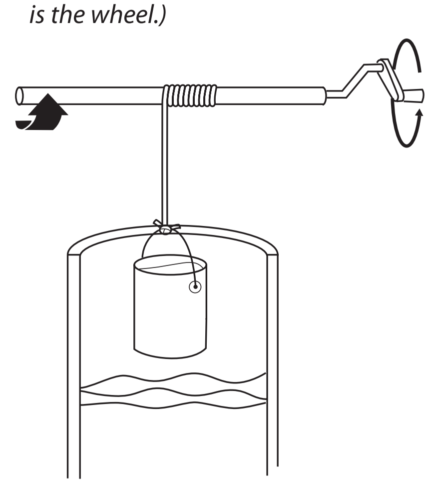
Provide each group with a paper cup filled with pennies or paper clips and ask them to feel its weight and then place the cup into the bucket of the well model. Use the following script to help the students explore the function of the wheel and axle.

**Steps**

1. Move two desks close enough together so that you can place one side of the well's base on one desk edge and the other side on a second desk edge. Put a book on each side to hold the model firmly in place. Lower the bucket to the floor. (See page 17 of the Building Instructions Booklet.)



- Ask the class to investigate the well by first locating the wheel and axle in the machine.
  *(The rod across the top is the axle. The crank, which turns in a circle, is the wheel.)*

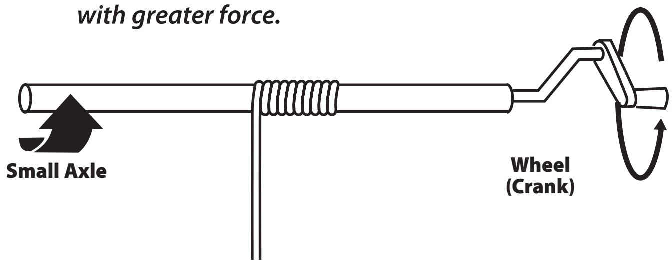


- The students should record in their journals the difference in the sizes of circumference of the wheel and axle. They should note which travels the further with one rotation. *(The wheel.)*

- Ask the following questions:

(a) Do you turn the wheel to make the axle go round? If so, the machine helps you complete the task by multiplying the force you apply.

***The large wheel turns through a long distance with a small amount of effort force, while the small axle turns through a small distance, but with greater force.***




(b) Or, do you turn the axle to make the wheel go round? If so, your machine helps you cover more distance at a faster speed.

***The small axle turns through a small distance using a large amount of effort, while the large wheel rotates through a large distance with a small amount of effort.***

**Students should discover that they turn the wheel to make the axle rotate.**

(c) Ask the students to determine exactly how the well works.

***When you provide effort by turning the crank, the rod turns, winding up a rope to raise the bucket, which is the resistance or load. This simple machine makes lifting the bucket much easier than just hauling on the rope by hand.***

**2.** (a) Start with the blue rod facing up and turn the wheel all the way around to lift the bucket. Be careful not to let go of the rod as you turn, or the string will quickly unwind and the bucket will drop.

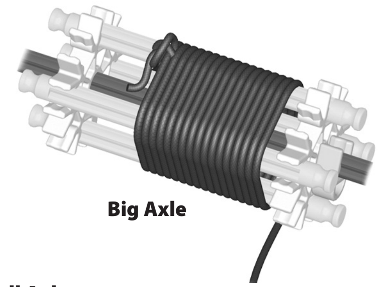
(b) Count the number turns it takes to raise the bucket from the floor to the top of the desk. Each time the blue rod faces up it has completed one turn. Record this number.

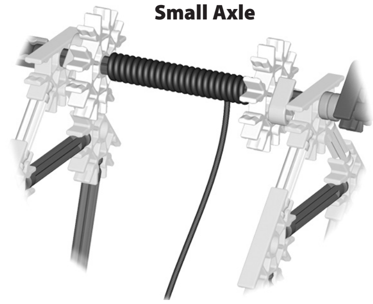
(c) How far does the bucket move each time you turn the wheel (crank)?

(d) How could a wheel and axle in a real well make it easier for you to lift a filled bucket?

***Depending on the height of their desks, it should take about 5-7 turns of the crank to lift the bucket to the desktop. For each full rotation of the wheel, the bucket moves the same distance as the circumference of the axle. Students should realize that it would be easier to turn the wheel of a real well than it would be to haul the bucket up on a rope.***

**3.** (a) Remove the yellow rods from the axle and attach the string to the red rod that now forms the axle. (See Small Axle picture on page 17 of the Building Instructions Booklet.)




(b) Lower the bucket to the floor again.

(c) Count the number of turns it takes to raise the bucket from the floor to the top of the desk. Record this number.

(d) What do you notice as you turn the wheel to lift the bucket?

(e) Compare the number of turns to raise the bucket for the two axles?

(f) Which axle was easier to turn?

(g) Why?

***Again, depending on the desk height, it should take about 20-22 rotations to raise the bucket to the desktop. Students should notice that it takes many more turns to lift the bucket using the small axle than the big axle. Students will find that the small axle made it easier to lift the bucket because they had to apply less effort to turn the wheel with the small axle than with the big axle. However, they have to turn the wheel more times. Using a wheel to turn a small axle is easier than using the same size wheel to turn a larger axle.***

## Class Idea

Set up the building activity so that one half of the class makes the model with the yellow rods for the axle and the other half makes it with the single red rod. Then ask the students to move from one model to the other to discover which type of axle requires the most effort to raise the bucket.

4. (a) Change the size of the wheel by using longer and shorter rods and then repeat the experiment.
   (b) How do the other rods compare with the blue rod?
   (c) Do they make it easier or harder to lift the bucket?
   (d) What does this tell you about how the size of the wheel affects your work?

   ***Students should notice that using longer rods for the wheel will make it easier to turn the axle. Shorter rods will make it harder to turn the axle. If your class has already explored levers you can explain that a wheel and axle works as a lever that rotates and tie in their knowledge about how the length of the lever arm affects the work carried out.***

## Applying The Idea

- Ask the students to write about the advantages and disadvantages of both axles and the different size wheels in their journals.

  ***The small axle is easier to turn but it requires more turns to lift an object. The big axle takes fewer turns but it needs more effort to turn it. The bigger the wheel, the easier it is to turn the axle but you have to turn it through a greater distance.***

- Encourage them to discuss situations where the different sizes would be appropriate.

  ***You may use a small axle in a situation where you need to lift something heavy and you want the wheel to turn easily. You may use a big axle if you want to lift something quickly that is not very heavy.***

- Ask the students to decide which combination of wheel and axle will make it easiest to lift the bucket.

  ***The largest wheel and the smallest axle.***

- Ask the students to build and test other sizes of wheels and axles to validate their findings.

## Extending The Idea

1. (a) Use a spring scale to measure the effort force you applied to lift the cup in the different situations in the activity. Attach the scale to the cup to measure the effort force required to lift it without the well's wheel and axle mechanism.
   (b) Snap a purple connector to the end of the blue rod that forms the crank (handle) of the well. Hook the spring scale onto the purple connector. Pull the spring scale straight up to lift the handle in each of the different situations in the activity.
   (c) Record and compare readings. Use them to determine which wheel and axle system requires the least, and which requires the most, effort. Explain your answers.
   (d) Calculate the work done by this simple machine. This can be calculated using the following formula:

   **Output Work =**
   **Weight of the bucket x Distance it moves**

2. Ask the students to calculate the Mechanical Advantage of the wheel and axle combinations they have built. Use the following directions:
   (a) Measure the diameter of the wheel or the axle – whichever one provided the **effort.** Then divide the diameter in half to get the effort radius (**ER**).
   (b) Measure the diameter of the wheel or axle – whichever one isn't providing the effort. Then divide this diameter in half to get the resistance radius (**RR**).
   (c) Divide the ER by the RR to find the Mechanical Advantage (**MA**).

   **ER ÷ RR = MA**

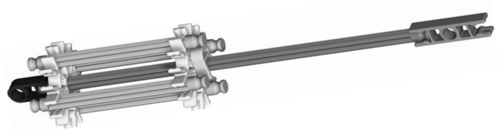
   ***In the example of the well, where the wheel turns the axle, the MA = Radius of Wheel ÷ Radius of Axle. The calculation will result in a Mechanical Advantage of more than 1, indicating that the simple machine makes work easier by multiplying the force.***

## JOURNAL CHECK:

At each stage, ask the students to keep individual journals to record their findings.
The following experiments, measurements and labeled diagrams should be recorded:

- ✔ Identification of wheel and axle (including a diagram).
- ✔ Description of how the well works.
- ✔ Number of turns to raise the bucket using various sizes of axles.
- ✔ Effort force required to raise the bucket using various sizes of axles and wheels.
- ✔ A table, such as the one shown below, to summarize their findings.

| SMALL AXLE | LARGE AXLE | SMALL WHEEL | LARGE WHEEL |
|---|---|---|---|
| More turns to lift bucket | Fewer turns to lift bucket | Travels small distance | Travels longer distance |
| Less effort to turn | More effort to turn | Harder to turn axle | Easier to turn axle |



# THE SCREWDRIVER:

## An example of a wheel turning an axle

## OBJECTIVES

**Students will:**

1. Identify the parts of a wheel and axle simple machine.
2. Investigate, demonstrate, and explain how a wheel turning an axle makes work easier.
3. Determine the mechanical advantage of a screwdriver (wheel and axle) system mathematically.
4. Determine the mechanical advantage of a screwdriver experimentally.

## MATERIALS

**Each group of students will need:**

- Building Instructions Booklet and K'NEX parts
- Small paper cups (3 oz. is recommended) 1 per group
- Pennies minted after 1982 (30 per group)
- Masking tape
- String
- Meter sticks or meter tapes
- Student Journals
- Pre-built model screwdriver and a gray rod for the introductory activity

## PROCEDURE

### Introduction

- **Teacher Note**: This lesson will deal with the screwdriver as a wheel and axle simple machine. It is possible that students may mention the fact that the screwdriver can be used as a lever. To open paint cans for example. Do not discourage these comments but emphasize that this lesson will deal with the wheel and axle applications of the screwdriver.

- The students were introduced to wheel and axle simple machines in the previous lesson.

  ***The Well.***

- Introduce the K'NEX screwdriver model that was pre-built for your demonstration. Ask students to identify the parts of this simple machine.

  ***Wheel, axle.***

- Ask where the effort force is applied to the screwdriver?

  ***To the handle (wheel).***

- Ask where the resistance or load meets the screwdriver?

  ***At the end of the blade on the shaft (axle).***

- Select a student to come to the front of the room. **Do not select the strongest person in the class.** Hold up the gray K'NEX rod. Show the class that the rod is identical to the gray rod in the screwdriver model. Tell them you are going to hold one end of the gray rod tightly and that their classmate is going to try to turn the rod using one hand. Hold the rod as tightly as you can and ask the student to try to turn the rod. The student's task will be very difficult if not impossible. Now, propose that they try to turn the gray rod on the screwdriver as you hold the end of it. Remove the orange connector from the end of the screwdriver and hold the shaft (gray rod) as before. Instruct the student to turn the handle of the screwdriver. They will be able to turn the gray rod on the screwdriver easily and you will not be able to keep it from turning. Ask students why it was so easy to turn the gray rod when it was attached to the screwdriver.

  ***Answers will vary. Encourage students to arrive at an answer that highlights that the screwdriver is a simple machine that multiplies force.***
  ***The student was actually able to use less force with the screwdriver and they could turn the rod easily in your hand. Therefore the machine multiplied their force.***

- Provide students with background information on the concepts of work, force, effort, resistance, and load (See Key Terms and Key Concepts on pages 39-41 of this Guide).

  Ask students to analyze the class demonstration by answering the following questions in their journals.

  - Identify the effort force used to turn the screwdriver.

    ***The effort force is provided by the student's hand.***

- Identify the wheel, axle, and resistance in the screwdriver.

  ***The resistance is the teacher's hand, the wheel is the handle, and the axle is the shaft of the screwdriver.***

- Explain whether the screwdriver multiplied force or distance.

  ***Multiplied force – The screwdriver multiplied the effort force because the student could not turn the rod without it.***

- Explain whether or not the screwdriver changed the direction of force.

  ***It did not. The gray rod turned the same direction the handle turned.***

- Explain whether or not the student did work during the demonstration.

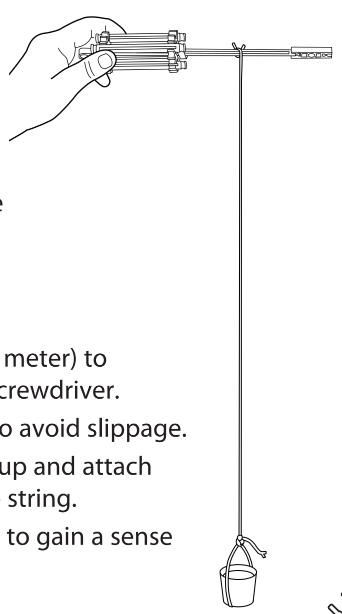
  ***Yes and no! They didn't do work in the first trial because even though they applied a force, the rod did not move. In the second attempt, force was applied and motion resulted so work was done.***

## BUILDING ACTIVITY

- Distribute the Building Instructions Booklets and instruct groups of 2 -3 students each to collect the K'NEX pieces to build the **SCREWDRIVER**. (page 18)
- The screwdriver can be built quickly by the students.
- Remind students to maintain careful records of their observations, answers to questions, and calculations throughout this lesson in their journals.

## INQUIRY ACTIVITY:
## How does the screwdriver make work easier?

**Provide each group with**



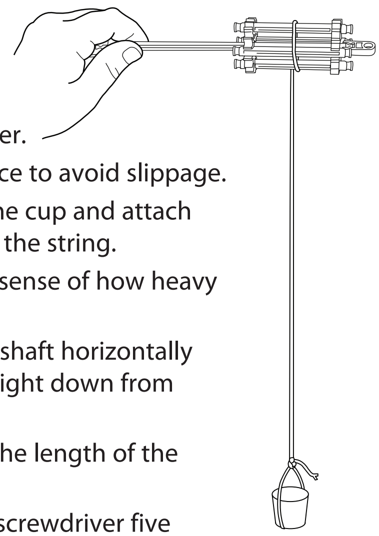
- a small paper cup
- 30 pennies
- masking tape
- meter stick or meter tape
- string or twine

**Instruct students to:**

**Part I**

- Tie the string (about one meter) to the shaft of their K'NEX screwdriver.
- Tape the string in place to avoid slippage.
- Place 30 pennies in the cup and attach the cup to the end of the string.
- Lift the cup several times to gain a sense of how heavy it feels.
- Hold the screwdriver handle horizontally so the cup hangs straight down from the shaft.
- Measure and record the length of the string.
- Turn the handle of the screwdriver five times to raise the cup.
- Gain a sense of how much effort is required to lift the cup.
- Measure and record the length of the string after the handle has been turned. Subtract this measurement from the previous measurement of the string to see how far the cup was lifted.

**Part II**



- Tie the string (about one meter) to the handle of their K'NEX screwdriver.
- Tape the string in place to avoid slippage.
- Place 30 pennies in the cup and attach the cup to the end of the string.
- Lift the cup to gain a sense of how heavy it feels.
- Hold the screwdriver shaft horizontally so the cup hangs straight down from the handle.
- Measure and record the length of the string.
- Turn the shaft of the screwdriver five times to raise the cup.
- Gain a sense of how much effort is required to lift the cup.
- Measure and record the length of the string after the shaft has been turned. Subtract this measurement from the previous measurement of the string to see how far the cup was lifted.

**Ask students to respond to the following questions**

- Did you use more force to lift the cup of pennies with your hand or to turn the handle to lift the cup?

  ***Less force to turn the handle.***

- Did you use more force to lift the cup of pennies with your hand or to turn the shaft of the screwdriver to lift the cup?

  ***More force to turn the shaft.***

- Do your answers to the questions above mean the simple machine multiplies force when you turn the handle? Explain.

  ***Yes, it multiplies force. The handle acts as a wheel in this system and the shaft acts as an axle. Turning the handle required less effort force so the machine must have multiplied the force applied.***

– Do your answers to the questions mean the simple machine multiplies force when you turn the shaft? Explain.

*No, it took much more force to lift the cup by turning the shaft.*

– How much did the length of the string change when you lifted the cup by turning the handle?

*It changed by several centimeters.*

– How much did the length of the string change when you lifted the cup by turning the shaft?

*It likely changed by more than 20 centimeters.*

## Applying the Idea

- Help students to understand that they can use the distances from their experiment to determine how much the screwdriver multiplies force. By dividing the distance the cup on the shaft was lifted into the distance the cup on the handle was lifted.

For example:

If the cup tied to the shaft rose six centimeters and the cup tied to the handle moved 30 centimeters you can divide using the formula below. Your answer will indicate how many times your screwdriver multiplies force. This value is called the **experimental mechanical advantage** as the distances were gathered during an experiment.

$$MA = \frac{\text{Distance the string on the handle moves}}{\text{Distance the string on the axle moves}}$$

$$MA = \frac{\text{30 centimeters}}{\text{6 centimeters}}$$

$$MA = 5$$

Which means the simple machine multiplies force 5 (five) times.

- Instruct students to use the distances they computed in the "Inquiry Activity" and the formula above to find the experimental mechanical advantage of their screwdriver.

## Extending the Idea

- Mechanical advantage can also be calculated mathematically without the need to complete an experiment. This calculation identifies the **ideal mechanical advantage** for the wheel and axle simple machine. The formula for this calculation is:

$$MA = \frac{\text{Diameter of the Wheel (Handle of the Screwdriver)}}{\text{Diameter of the Axle (Shaft of the Screwdriver)}}$$

**Teacher Note:**

The actual formula is:

$$MA = \frac{\text{Radius of the Wheel}}{\text{Radius of the Axle}}$$

Measuring the radii of the handle and shaft of the model screwdriver may be a challenge for students. Using the diameters will make the measurements easier to collect and provide the exact same mechanical advantage.

- Ask students to gather measurements from the model and compute the ideal mechanical advantage for their screwdriver model.

  *Answers in the classroom will vary due to measurement variations but should be similar.*

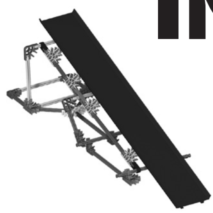
- Students have determined an experimental mechanical advantage and an ideal mechanical advantage for their screwdriver model. Ask students to compare the values they determined.

  *The two values for each group will vary but they should be close to one another. This is an excellent opportunity to discuss measurement error and experimental error. Many factors may have affected the results of the students' findings (measurement errors while finding the diameters of the handle and shaft; measurement errors finding the distances the cups rose during the experiment; the strings may have stretched slightly as the cups were lifted; the strings may have wound over one another on the shaft of the handle or shaft; etc.). Any of these things may have caused differences in the mechanical advantage values.*

## JOURNAL CHECK:

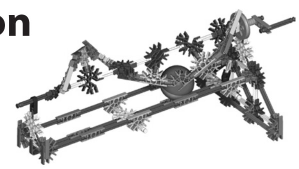
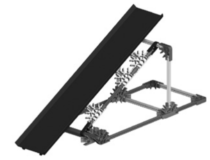
Students were directed to keep individual journals to record their findings. The following should be included in their journals:

- ✔ Questions answered during the introductory activities.
- ✔ Questions answered during the Inquiry Activity.
- ✔ Calculations of the experimental mechanical advantage.
- ✔ Calculations of the ideal mechanical advantage.
- ✔ Questions answered during the "Extending the Idea" activities.

# INCLINED PLANES

## Background Information

## OBJECTIVES

### Students will:

1. Investigate the characteristics of inclined planes to understand how they work.
2. Recognize that screws and wedges are types of inclined planes.
3. Investigate how the use of an inclined plane affects work in relation to force, distance, speed, and direction.
4. Demonstrate how the force needed to move a load up an incline depends on the slope of the incline.
5. Construct different types of inclined planes and demonstrate how they function.
6. Analyze objects/tools in terms of their application as inclined planes.

## KEY TERMS and DEFINITIONS for the teacher

The following is intended as a resource for the teacher. The age of the students, their abilities, their prior knowledge, and the curriculum requirements will determine which of these terms and definitions you introduce into your classroom activities.

**Simple Machine:**
A simple tool that makes work easier to do. Simple machines make work easier by changing the way in which the work is done, not by changing the amount of work that is needed.

**Inclined Plane:**
A flat surface with one end higher than the other. It is used to lift a load through a vertical distance.

**Screw:**
A rod, called the body, with an inclined plane spiraling around it. The inclined plane forms ridges, called threads, around the body of the screw. It is used to lift an object or fasten two objects together.

**Wedge:**
A device made of 2 inclined planes arranged back to back. It is used to move one object in relation to another object.

**Force:**
Any kind of push or pull applied to an object.

**Work:**
The task being undertaken when using an inclined plane. In science, work refers to the use of force to move a load (object). It can be defined as follows:

$$W = F \times d$$

Where **W** = work
**F** = the force (effort) applied to the task
**d** = the distance the load (object) moved

**NOTE:** If the object has not moved, work has not been done.

**Effort:**
The force that is applied to move a load or overcome a resistance (ie: do work.) The force applied to a simple machine is called the effort force.

**Resistance:**
The force exerted by the object upon which one is trying to do work; it works against the effort.

**Load:**
The object (weight) moved or the resistance that is overcome when using an inclined plane. It exerts a force (resistance) against the inclined plane and the effort.

**Slope:**
A measure of the steepness of an incline.

**Friction:**
The force caused when 2 surfaces rub together as an object moves.

**Mechanical Advantage (MA):**
A mathematical calculation that indicates how many times the simple machine multiplies the effort force. For an inclined plane it can be calculated using the following formula:

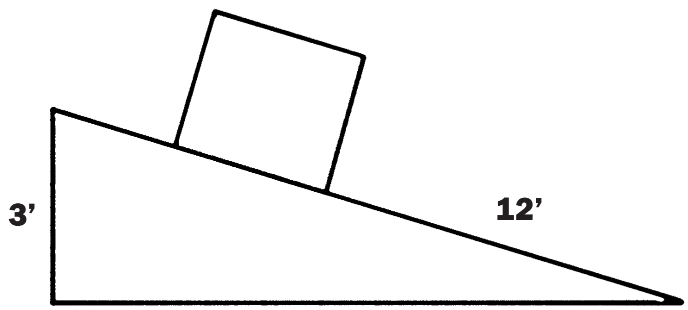
$$\frac{\text{Slope length}}{\text{Slope height}} = MA$$

(**NOTE:** Measuring the length of a screw will require measuring the distance around the thread.)

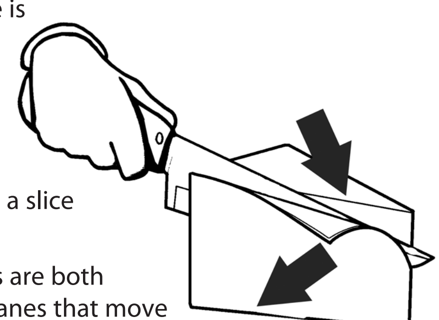
Mechanical Advantage is always expressed as a number without a unit. EG: MA = 2

## KEY CONCEPTS

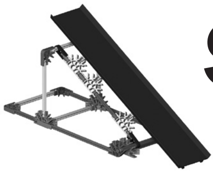
- An inclined plane is used to lift a load through a vertical distance. Rather than lifting an object straight up, which requires effort equal to the weight of the load, you increase the distance over which you do the work. In the diagram below, the sloped distance is 4 times longer than the vertical distance. To move an object along the inclined plane 1/4 of the effort will be needed compared to moving the object vertically. That effort, however, must be sustained over a longer distance (12′ compared to 3′.)



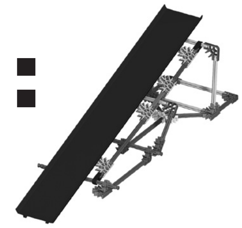

- The longer the slope of the inclined plane, the less force is needed to complete the task.
- The ***work,*** however, that is done to move a load along the inclined plane is the same as the work that is done to lift the load vertically (if we disregard friction.)
- Objects are moved along the slope of the inclined plane; the inclined plane does not normally move.
- Inclined planes can also be used to control the rate of descent of an object from a height.
- Screws increase the distance over which you apply the effort force, but reduce the amount of effort force needed. The distance around the threads of a screw is longer than the length of the screw itself. This means that traveling around the threads of the screw is longer, but easier than traveling straight up. For example, it requires less effort to climb a spiral staircase than it does a ladder, but you climb more steps and cover a greater distance to get to the same place.
- Wedges change the direction of the applied force and increase the force on the objects being separated; when pushing down on a wedge, the object it is pushing against moves sideways so that the direction of the two forces is at right angles to each other.
- If the wedge is long and thin, it separates the sides of the object it is being driven into a small distance with a small applied effort force. If the wedge is short and fat, the sides of the object will be separated a greater distance but to achieve this will require a greater applied effort force.
- The blade of a knife is a wedge. As the blade (wedge) is pushed down through, for example, a piece of cheese, it separates a slice from the block.



- Wedges and screws are both types of inclined planes that move in order to carry out their functions.



# STEEP & LONG RAMPS:



**Examples of inclined planes**

## OBJECTIVES

**Students will:**

1. Investigate the characteristics of an inclined plane.
2. Understand how the use of an inclined plane affects work in relation to force, distance, speed and direction.
3. Compare inclined planes with different angles to determine the effort needed to raise an object.

## MATERIALS

**Each group of students will need:**

- Building Instructions Booklet and K'NEX parts
- Ruler/tape measure
- Tape
- 3 secured rolls of pennies, gram weights or other weighted objects (Make sure you select objects that are heavy and that, if using rolls of pennies, the 3 rolls are firmly secured before you distribute them to the students.)
- A piece of heavy rubber band, approximately 4-6 inches (10-15 cms.) long
- Student Journals
- 400 gram or 10 Newton spring scale (optional)

## PROCEDURE

### Introduction

- Review with the students the way in which simple machines help do work – not by changing the amount of work that is needed but by changing the way in which it is done.
- Ask the students to consider an activity that they do every day, namely moving themselves, or an object, from one level to another. What do they use to help them? (*Stairs, steps, ladders, ramps.*)
- Explain that the students will be investigating a simple machine, the **inclined plane**, that allows them to use less effort to move an object up or down, although they will need to move the object over a longer distance than if they were lifting it vertically.
- Provide the class with a definition of an inclined plane and draw a diagram on the board to shown its features.

- Ask the students to think about places where they have seen inclined planes (ramps) used to move a person or an object to a higher position.

  ***Ramps in the sidewalk for wheelchairs;***
  ***ramps to load heavy objects onto trucks;***
  ***ramps between levels in a mall or sports stadium.***

- The school building should provide examples of wheelchair ramps and possibly a ramp at a loading dock. If possible, take the children to investigate them. They should note the steepness of the ramp; suggest reasons why the ramp was used in that particular location; and understand that, whether they step up onto the curb (or steps), or use the ramp, they have moved vertically and arrived at the same place. Ramps simply make it easier to get to that place.
- Encourage the students to use the library or Internet to investigate how inclined planes are used.

  For example: Macaulay, D. The Way Things Work.
  Or visit http://www.professorbeaker.com/plane_fact.html

## BUILDING ACTIVITY

- One half of the student groups will build the Steep Ramp and the other half, the Long Ramp.
- Ask the groups to turn to pages 19-21 of the Building Instructions Booklet and construct the models of the **STEEP RAMP** and the **LONG RAMP**.
- Building Tip for step 7 for the **LONG RAMP**. Slide the first section of the ramp over the yellow connectors. Then slip in the white joining plate to the end of the first section of ramp. Finally, slide the second section of ramp over the yellow connectors until it meets the white joining plate. Slide it over the joining plate to close the gap and complete the entire length of ramp.
- **NOTE:** Make sure that both models are constructed so that the bottom end of the black plastic ramp touches the desktop. Both ramps are designed to move an object through the same vertical distance and to ensure this, correct positioning on the support structure is essential.

## INQUIRY ACTIVITY:

### How does the inclined plane help make work easier?

- Explain that they will be investigating the K'NEX Steep and Long Ramps by pulling different objects up them. Remind the students that the purpose of the inclined plane (ramp) is to make work easier by multiplying the amount of force applied to move an object.

**Steps**

**1.** (a) Measure the heights of the two ramps and the lengths of their sloping sides. What do you notice?

(b) Draw diagrams in your journals to represent the ramps and record your measurements on them.

***Students should notice that the vertical height of the two ramps is the same, but the length of the sloping side of one is longer than that of the other.***

**2.** (a) Give each group 3 rolls of pennies (or another weighted object,) and a 4-6 inch (10-15 cms.) length of heavy rubber band. (**NOTE:** *Before distributing the rubber bands, make sure the students understand that over-extending them can result in a snap back or loss of control; they need to be very careful. See Safety Information at the beginning of the Guide.)*

(b) Tie or securely tape the rubber band to the weight, making sure that there is a length for you to hold. One member of the group should hold this end of the rubber band and lift the weight vertically so that it is level with the top of the ramps. Notice how it feels to lift the weight.

(c) The other member of the group should measure and record the length of the stretched rubber band.

(d) What do you think the stretched rubber band shows?

***Students should say that it is difficult to lift the weight vertically. The stretched rubber band shows the amount of force needed to raise the weight through the vertical distance. Since the rubber band is very stretched, a large effort force is needed to lift the weight vertically.***

**3.** (a) Pull the weight up the slope of the steep (short) ramp. Hold the rubber band in exactly the same place as when you lifted the weight vertically (step 2.)

(b) Measure and record the length of the rubber band when the weight is almost at the top.

(c) How does this compare to lifting the weight without the ramp?

(d) What do you think this means?

***Students should notice that it is easier to pull the weight up the incline than to lift it vertically. Because of this the rubber band is less stretched when using the ramp. Students should notice a marked difference in the length of the rubber band when using the ramp. They should state that it takes less force to lift the weight using the ramp, which is why the rubber band is less stretched.***

**4.** (a) Pull the same weight up the slope of the long ramp. Again, measure and record the length of the rubber band when the weight is almost at the top.

(b) How does this compare to pulling the weight up the steep ramp?

(c) What does this show?

***Students should notice that the rubber band is even less stretched when using the long ramp than with the steep ramp. This shows that it takes less force to move something up a long, more gently sloping incline, than a short, steep one. However, you have to move it over a longer distance.***

## Applying The Idea

- Ask the students to write in their journals about other situations where they would use an inclined plane and why.
- When they have completed their writing ask them to share their ideas with the rest of the group. Encourage the students to discuss factors that may be involved in determining what the slope of the incline (gradient) should be. Ask them to consider situations where a short, steep slope is preferred, such as a sliding board or a roller coaster, and where a long, gentle slope is preferred, such as a mountain trail or wheelchair ramp.

- Ask the students to complete the following sentence describing the force needed to move an object up an inclined plane:

  **The steeper the slope of the inclined plane…**

  ***(the more force required to move the object up the incline.)***

- Their completed sentences should be written in their journals.

## Extending The Idea

**1.** (a) Determine the actual amount of force used to pull the weight up the inclined plane by using a spring scale. Attach the spring scale to the weight and conduct the experiments from step 2 again.

(b) In the activity, both the weight and the inclined plane had a smooth surface. Think about how friction can affect the work done with an inclined plane.

(c) Would a rough object moving along a rough inclined plane require more force to raise the object compared to simply lifting it?

(d) Would it require more force than moving a rough object up a smooth inclined plane?

(e) Would wheels on the object have any effect on the force required to move it up the incline? Why or why not?

(f) Conduct experiments to determine how friction affects movement on an inclined plane. For example, cover the ramps with a terry towel or similar cloth. Try to pull a wheeled vehicle up the incline. Discuss your findings.

**2.** Ask the students to calculate and compare the Mechanical Advantage of the steep ramp and the long ramp. This can be calculated using the following formula:

$$\frac{\textbf{Slope length}}{\textbf{Slope height}} = \textbf{MA}$$

### JOURNAL CHECK:

✔ Measurement of ramp lengths and heights with diagrams.

✔ Rubber band force measurements.

✔ Explanation of the benefits of gradual/steep inclined planes.

✔ List of examples of inclined planes and descriptions of how they help make work easier.

# THE SPLITTING WEDGE:

## An example of a wedge

## OBJECTIVES

**Students will:**

1. Explore how a wedge, a special type of inclined plane, can be used to move things apart.
2. Investigate how a wedge makes work easier by multiplying the amount of force applied and by changing the direction of the applied force.

## MATERIALS

**Each group of students will need:**

- Building Instructions Booklet and K'NEX parts
- Ruler
- 4 heavy books
- Student Journals

## PROCEDURE

### Introduction

- Review with the students how an inclined plane makes it easier to move objects from one height to another. Explain that they will investigate how they could use an inclined plane to move things apart.
- Encourage them to think about the way in which a knife cuts through an object. Demonstrate this using a piece of cheese or modeling clay. Ask the students to explain precisely what happens as they watch the process.

  ***As the knife goes through the cheese or clay, the 2 pieces separate and move away from the blade.***

- Explain that the blade of the knife is an example of a special type of inclined plane called a wedge.
- Provide the students with a definition and a diagram of a wedge. (See: Key Terms and Definitions. Pages 47-48)
- Ask the students to use the library or the Internet to investigate further and discover how a wedge is used. (For example, visit the following site for information: http://coe.uh.edu/archive/)

### BUILDING ACTIVITY

- Invite the students to build the **SPLITTING WEDGE** model (pages 22-23 of the Building Instructions Booklet.).
- Allow them a few minutes to investigate the model and determine what it does.

**NOTE:** *In the inset diagram of steps 1-6 it appears that the 2 sets of red rods are further apart at the top than at the bottom. This is not the case – they are parallel to one another. Only when the wedge is inserted do the upper edges move further apart.*

### INQUIRY ACTIVITY:

### How does the splitting wedge help you do work?

Review with the students the fact that wedges are actually inclined planes that move. Their purpose is to make work easier by multiplying the amount of effort force that is applied to do the job. The students will determine how they do this by using the model they have constructed.

**Steps**

1. Look at the splitting wedge. Think about why it is considered to be a type of inclined plane.

   ***The splitting wedge is made up of 2 inclined planes arranged back to back.***

2. (a) Set the edge of the splitting wedge (constructed in steps 7-11 of the building activity,) between the two sides of the 'log' so that it is approximately half way down the first set of blue rods.

   (b) Measure and record the distance between the top edges of the 'log'.

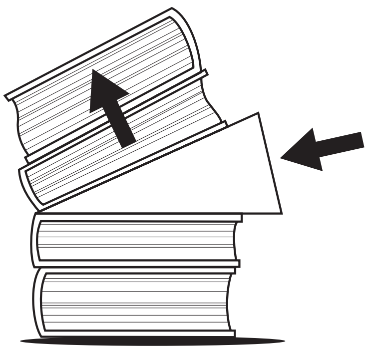
   (c) Push the wedge in further and measure again. What do you notice?

3. Draw and label a diagram to show in which directions the wedge and the 'log' halves have moved.

   ***Students should notice that as they push down, the sides of the 'log' move sideways. This should be reflected in their diagrams – the wedge makes the log's red connectors separate a greater distance than just the width of the wedge's tip. The more they push down, the further apart the log's sides separate. The sides of the log move at right angles to the movement of the wedge.***

4. (a) Take 4 heavy books. Stack them on top of each other. Using your fingertips, lift up two of them. Notice how this feels.
   (b) Now use the splitting wedge to lift the same two books.
   (c) When you tap in the wedge, which way do the books move?
   (d) How does this compare with moving the books with your fingertips?
   (e) Try the experiment again, this time lifting all four books.
   (f) What do you notice this time?

   ***Students should notice that it is much more difficult to lift the books using their fingertips than it is with the wedge, especially when they try to lift all four books. As the wedge goes in sideways, the books move vertically.***



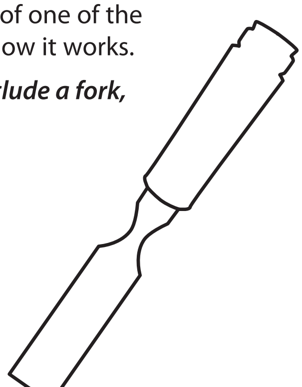

## Applying The Idea

- Ask the students to record in their journals how a splitting wedge functions as an inclined plane and also how it is different from the inclined planes in the previous activity.

  ***Students should note that wedges make it easier to raise objects up and this makes them like inclined planes. They are different because the wedge changes the direction of the force. Instead of an object moving up a slope, the slope (wedge) is moving under the object to lift it. Unlike most inclined planes, the wedge moves when it is used.***

- Encourage the students to think of other machines that function like a splitting wedge. Ask them to draw a picture or build a K'NEX model of one of the machines and explain how it works.

  ***Other examples include a fork, axe, chisel.***



## Extending The Idea

1. Using wedges, Abraham Lincoln earned himself a nickname, The Railsplitter. Use the library or Internet to research the life of Abraham Lincoln to find out how he got his name and how he used wedges.
   (Visit http://lincoln.lib.niu.edu/ for information about the early years in the life of Abraham Lincoln.)

   ***When Lincoln was a boy, he helped his father clear the land in a wooded area in Indiana, where he lived. He used an axe, a type of wedge, to cut trees. Later on in life, he worked for others chopping firewood for heating and cooking, cutting logs for houses and splitting rails for fences and cabins. To split a log into rails, he would drive a wedge into the log. He was given the nickname "The Railsplitter" when he ran for political office in 1860. It reminded voters of his background and helped them relate to him.***

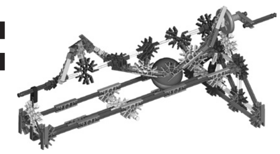
2. Ask the students to calculate the Mechanical Advantage of the K'NEX splitting wedge. This can be calculated using the following formula:

$$\frac{\textbf{Slope length x 2}}{\textbf{Thickness of the end you strike}} = \textbf{MA}$$

## JOURNAL CHECK:

- ✔ Diagram and definition of a wedge.
- ✔ Distance measurements.
- ✔ Diagram of the direction that work is performed, with labels for distance and direction.
- ✔ Explanation of how the wedge functions as an inclined plane and how it differs from other inclined planes they have used.
- ✔ List of everyday wedges, with diagrams.

# THE ARCHIMEDES SCREW:



## An example of a screw simple machine

## OBJECTIVES

### Students will:

1. Identify and diagram the various parts of the Archimedes screw model.
2. Describe the transfer of energy in an Archimedes screw system.
3. Investigate, demonstrate, and explain how an Archimedes screw makes work easier.
4. Calculate the mechanical advantage of the Archimedes screw model mathematically.

## MATERIALS

### Each group of students will need:

- Building Instructions Booklet and K'NEX parts
- Student Journals
- Ping Pong Balls
- Rulers
- String

## PROCEDURE

### Introduction

- Briefly review how an inclined plane multiplies force to make it easier to move/raise items to a higher level (i.e., a ramp used to move furniture into the back of a truck). Also, specialized inclined planes can be used to separate or split materials (i.e., the splitting wedge or the blade on an axe). Inform students they will be investigating how an inclined plane wrapped around a central cylinder or rod can be used to lift small items and fluids. This type of inclined plane is called a screw.
- Ask students if they have ever used a spiral staircase or a spiral ramp in a large building or sports stadium.

- Have students think about what would be easier; climbing a ladder to go up to the second floor to bed each evening or climbing a spiral staircase to get to the second floor. Allow time for the students to discuss the question with their group members.

  ***It would be easier to climb the spiral staircase because you use less force to climb each of the many short steps on the staircase. To climb the ladder, you climb fewer rungs than stairs but you must use a great deal more force with each rung you climb. It requires less effort to climb the spiral staircase than it does the ladder, but you climb more steps and cover a greater distance to reach the same height. This is an excellent opportunity to mention that the spiral staircase like other inclined planes is a simple machine that can multiply force.***

- Ask students what type of motion they complete as they walk up a spiral staircase or ramp.

  ***They walk in circles (rotational motion) but they move higher as they go (linear motion). Thus, the screw simple machine also changes the direction of force. To strengthen this concept, ask students what happens if they use a wood screw and a screwdriver. The force applied to the screw is rotational and the screw turns but the screw moves in a straight line (linear motion) into the wood.***

- Inform students that they are going to build and investigate a special screw known as an Archimedes screw. This screw is named after a very famous ancient scientist who may have invented it.

  ***Students may be asked to research the history of the Archimedes screw to add a historical perspective to the lesson.***

## BUILDING ACTIVITY

- Distribute the Building Instructions Booklets and instruct each group of 2 – 3 students to collect the K'NEX pieces to build the **ARCHIMEDES SCREW**. (pages 24-27)
- The Archimedes screw model will require that students pay particular attention to detail as they build. Monitor their progress as they work and provide assistance as needed when the students begin the process of adding the spiral shape to the screw.

## INQUIRY ACTIVITY:
## How does this machine change the direction of force?

**Steps:**

1. When the models are complete, allow the groups to explore and investigate their model. Encourage them to locate and identify the inclined plane, the rod it is wrapped around, and the crank. Ask them to identify which types of simple machines they find in this model.

   ***Two inclined planes: the ramp that the screw rests in; the spiral plane wrapped around the rod attached to the crank. The students may not realize that the ramp the screw rests on is also an inclined plane. The crank is also a wheel and axle simple machine.***

2. Instruct students to draw and label a diagram of the Archimedes screw model in their journals. Ensure the following are identified on the diagrams: crank, ramp, ball, and screw. Ask students to include arrows to show the direction of motion for each of the parts above.

3. Help the students understand how their model works by asking them to investigate the following questions.
   - Where is the effort force applied?

     ***The effort force is applied to the crank.***
   - What type of motion does the effort force produce?

     ***Rotational motion for the screw and the ball moves in a straight line (linear motion) up the ramp.***
   - Are the motion of the crank and the motion of the screw the same?

     ***Yes! They are both the same type of motion: rotational.***
   - How is the effort force transferred through the model to move the ball?

     ***The effort force is applied to the crank which turns the screw. The threads of the screw push the ball up the ramp to the top of the system.***
   - Ask students to investigate and discuss the following with their group members.
     - How can you control the speed of the ball moving up the ramp?

       ***By turning the crank at different speeds.***
     - Does the screw turn at the same speed as the crank?

       ***Yes!***
     - Is it easier to turn the axle attached to the crank when the crank is in place or when the crank is removed?

       ***It is easier when the crank is in place. The crank and the axle form a wheel and axle simple machine that multiplies the force applied to the crank.***
     - How many times must you turn the crank to bring the ball to the top of the ramp?

       ***You must turn the crank 3 times to raise the ball.***

4. Ask the students whether or not the Archimedes screw changes the direction of force.

   ***It changes the direction of force: the rotational motion of the crank and screw cause the ball to move in a straight line (linear motion).***

## Applying the Idea

- Students will make measurements of the Archimedes screw model to mathematically determine how many times this simple machine multiplies force (mechanical advantage).
- Provide the students a length of string (50 cm or longer) and a ruler or meter stick.
- Instruct students to allow the ball to sit at the bottom of the Archimedes screw. Hold the ruler firmly so the beginning of the ruler is at a point approximately at the center of the ball. While one student holds the ruler in place, instruct a second student to move the ball to the top of the ramp. The first student will then note the distance from the center of the ball at the bottom of the screw to the center of the ball at the top of the screw.

  ***This measurement is the distance that the screw can move the ball along the ramp.***
- Ask students if it will be easy to measure the length of the inclined plane that wraps around the rod that goes down the center of the screw. Essentially, they must measure the edge of the thread that turns around the Archimedes screw.

  ***After discussing some student responses, suggest that students use string to gather their measurement. They can hold the string along the edge of the thread of the screw and hold it in place as they extend the string further and***

***further. They can then measure and record the length of string they used to go from one end of the screw to the other. This process will not provide an exact answer but it will provide a reasonable approximation of the length of the inclined plane portion of the screw.***

- Provide students with the formula that will allow them to determine the MA of the Archimedes screw.

$$\frac{\textbf{Length of the screw}}{\textbf{Distance the object moves}} = \textbf{MA}$$

- Tell students to use this formula and the data they collected to determine the mechanical advantage of the Archimedes screw.

  ***Students will divide to determine the answer. The answer indicates how many times the screw multiplies the applied force.***

- List the results of the various groups on the board. Discuss the results with the students. Should all of the results be similar or different?

  ***The measurements should be very similar. Each group had the same model and thus the measurements should have been the same and the results of the division problem should be essentially the same. Slight differences will appear due to measurement variations. Large differences indicate a mathematics error or a measurement error. This is an excellent opportunity to discuss experimental error.***

- Review what the students have learned. Ask students to demonstrate and explain how an Archimedes screw changes the direction of force. Ask students to demonstrate and explain how an Archimedes screw multiplies force.

## Extending the Idea

- Inform students that they are going to determine how the mechanical advantage of the system would change if there were changes made to the model.

  ***Remind students that they are to keep careful notes of their work and any calculations they make in their journals.***

- Ask students to determine the MA of an Archimedes screw whose ramp was just as long as the one on their model but the screw itself was 1½ (one and one half) times longer than the screw on their model.

  ***Since the length of the screw is on the top of the formula, the MA they find should be larger than the MA they determined for the original model.***

- Ask students to determine the MA of an Archimedes screw whose ramp is twice as long as the one on their model and the screw is twice as long as the one on their model.

  ***The answers will be the same as their original models. Both the top and the bottom lines of the formula were increased by the same factor so the division will result in the same value.***

- Challenge students to write a rule about the MA of the Archimedes screw based on their investigations.

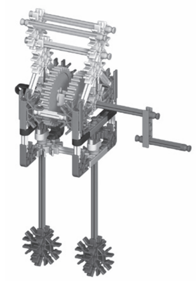
  ***The MA of an Archimedes screw depends on the length of the ramp and the length of the screw. If the length of the screw increases and the length of the ramp remains the same, the MA will always increase.***

**OPTIONAL EXTENSION:**

Ask two groups to work together to see if they can make a longer Archimedes screw, operate it successfully, and determine its MA.

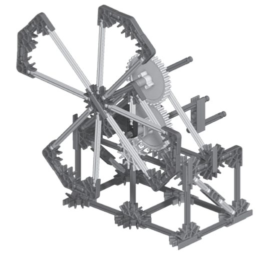
## JOURNAL CHECK:

- ✔ Diagram of the Archimedes screw model with labels and directional arrows.
- ✔ Record of student observations and answers to questions asked of students.
- ✔ Mathematical calculations of mechanical advantage.
- ✔ Details and calculations of "Extending the Idea" scenarios.
- ✔ The student's rule related to the MA of Archimedes screws.



# GEARS

## Background Information



## OBJECTIVES

**Students will:**

1. Investigate the characteristics of gear systems to understand how they work.
2. Describe the relationships between the parts of a gear system.
3. Construct different types of gear systems and demonstrate how they function.
4. Understand how differences in gear size within a system affect speed and force output.
5. Identify how rotational motion changes into linear motion using different gear systems.
6. Identify how the use of a gear system affects work in relation to force, distance, speed, and direction.
7. Analyze objects/tools in terms of their application as gear systems.

## KEY TERMS and DEFINITIONS for the teacher

**The following is intended as a resource for the teacher.** The age of the students, their abilities and prior knowledge, and your curriculum requirements will determine which of these terms and definitions you introduce into your classroom activities. These terms are not presented as a list that students copy and memorize. Rather, they should be used to formalize and clarify the operational definitions your students develop during their investigations. Students should be encouraged to use the appropriate terms in context as they write about their discoveries in their journals.

**Simple Machine:**
A simple machine is a device that transfers energy in a single motion. Simple machines make work easier by changing the *way* in which work is done. A simple machine does not, however, reduce the amount of work that is needed to do the job.

**Force:**
Any kind of push or pull applied to an object.

**Effort:**
The force that is applied to move a load or overcome a resistance (i.e. the force that is applied to do work.) The force applied to a simple machine is called input or effort force.

**Resistance:**
The force exerted by an object against the effort force.

**Work:**
In science, work refers to the amount of force used to move a load (object) through a given distance. Work can be defined as follows:

$$W = F \times d$$

Where **W** = work

**F** = the force (effort) applied to an object

**d** = the distance through which the force is applied

**NOTE:** If the object has not moved, work has not been done.

**Gear:**
A wheel with teeth around its outer rim.

**Gear Train:**
Two or more gears that interlock or mesh together form a gear train. As one gear turns, its teeth push against the teeth of the adjacent gear causing the second gear to turn in the opposite direction.

**Driver Gear:**
The gear to which the effort force is applied. The driver gear transfers the effort force to the next gear in a gear train, the driven gear.

**Driven Gear:**
The gear that moves the load.

**Idler Gear:**
This gear makes those on either side of it rotate in the same direction.

**Mechanical Advantage (MA):**
*(Appropriate for students whose Math skills allow them to understand and work with fractions.)*

A mathematical calculation that indicates how many times a machine multiplies effort force or speed. For a gear system, mechanical advantage can be calculated using the following formula:

$$\frac{\textbf{Number of teeth on the driven gear}}{\textbf{Number of teeth on the driver gear}} = \textbf{MA}$$

Because the units (teeth) cancel each other out, mechanical advantage is always expressed as a number without a unit.

For example: $MA = \frac{\textbf{16 teeth}}{\textbf{8 teeth}} = \textbf{2}$

**Gear Ratio**

*(Appropriate for students whose Math skills allow them to understand and work with fractions and ratios: generally Grade 5 or above.)*

A ratio of the speed of rotation of the driver gear in a gear train to that of the driven gear. It can be calculated by comparing the number of teeth on the driven gear to the number of teeth on the driver gear in the train.

$$\text{Gear ratio} = \frac{\text{Number of teeth on driven gear (84)}}{\text{Number of teeth on driver gear (14)}} = \frac{6}{1} = 6:1$$

**Sprocket**

A toothed wheel on which a chain runs.

**Chain and Sprocket**

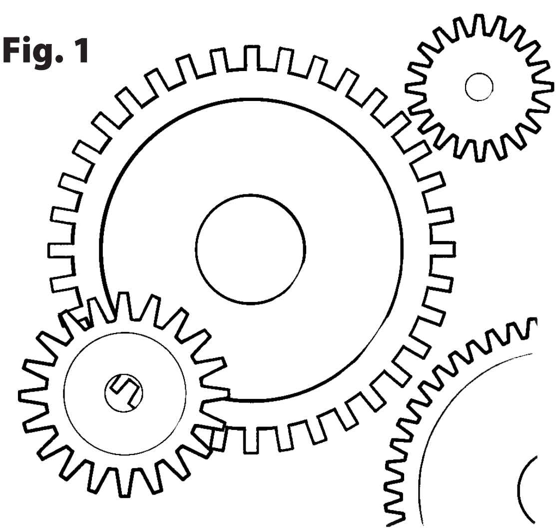
The driver system used to transmit rotary motion from a driver axle to a driven axle. The links of the chain mesh with the teeth on a sprocket.

## KEY CONCEPTS

The following summarizes some of the key concepts associated with gears and is offered here as **a resource for the teacher.** You may find some of this information helpful as you prepare your classroom activities.

- Gears are used to transfer motion and force from one location to another. These may be transferred directly through physical contact between gears in a gear train or transferred over a distance by a chain or belt that connects two or more gears.

**Fig. 1**

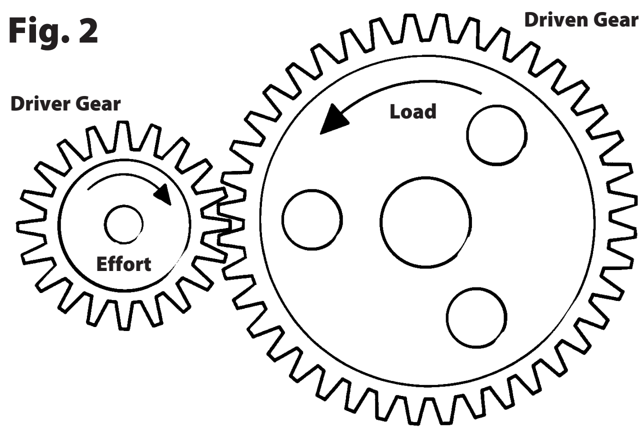


**Gear: A wheel with teeth around its outer rim.**

- In order to work, the teeth on gears must interlock or be connected by a chain or belt. A **simple gear train** comprises two or more meshed gears with only one meshed gear on each axle.
- The gear wheel to which the effort is applied is called the **driver gear.** In the K'NEX Crank Fan model, the driver gear is the gear that is attached to the crank axle. The driver gear transmits turning forces to the **driven** (or follower) **gear** causing it to rotate in the opposite direction.
- The force applied to the driver gear is the effort force or input force; the driven gear produces the output force.
- <u>Key fact about simple gear trains:</u> In a simple gear train with two gears of the same size, the driven gear turns at the same speed as the driver gear, but in the **opposite** direction.
- **Gear systems may make work easier:** Gear systems can make work easier by making things easier to move. They can do this in the following ways:

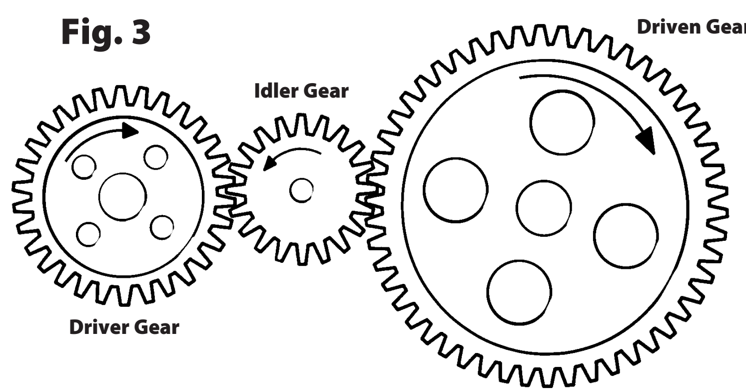
  **Transfer motion and force from one location to another.** When a twisting force, known as **torque**, is applied to the driver gear, its teeth transfer force and motion to the teeth of the adjacent driven gear. An example of this application is found in a salad spinner.

**Fig. 2**




  **Change the direction of rotational motion.** Adjacent gears in a gear train spin in opposite directions relative to each other. In gear trains made up of odd numbers of gears, however, the direction of rotational motion of the driven gear is the same as the direction of rotational motion of the driver gear. Examples of this use can be found in an eggbeater and in the mechanism of a clock.

**Fig. 3**

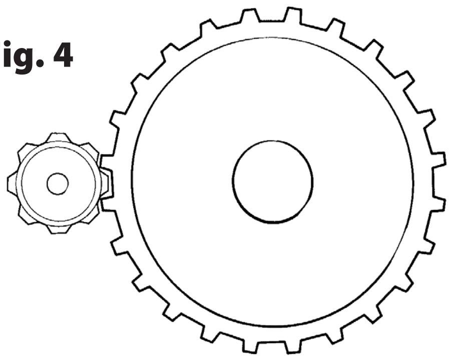



**Gear train with an odd number of gears.**

**Multiply the force applied to do a job.** Using different sized gears in a gear train or sprockets wrapped by a chain, affects the output **force** of the driven gear. A small gear driving a larger gear multiplies force at the expense of speed.

*(Appropriate for use with students whose Math skills allow them to understand and work with fractions and ratios.)*

**Fig. 4**



$$\text{MA} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driver gear}} = \frac{24}{8} = 3$$

**When mechanical advantage is greater than 1, effort force is multiplied by the gear system.**

**Change the output speed of a system.** Using different sized gears in a gear train or sprockets wrapped by a chain, affects the output **speed** of the driven gear.

## Speeding Up

A large driver gear turning a small driven gear increases the turning speed of the axle attached to the driven gear.

*(Appropriate for use with students whose Math skills allow them to understand and work with fractions and ratios.)*

For example, an 84-tooth driver gear will make 1 (one) complete turn for every 6 turns made by a 14-tooth driven gear. Therefore, the driven gear will turn six times faster than the driver gear.

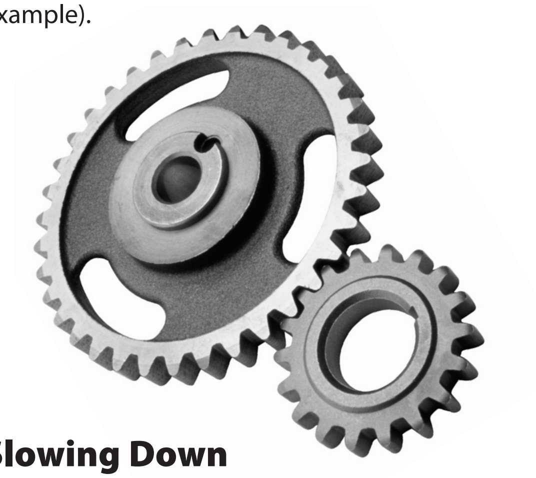
The Mechanical Advantage for this gear train would be 1/6. The gear ratio for this gear train would be:

$$\text{Gear Ratio} = \frac{\text{Number of teeth on the large gear}}{\text{Number of teeth on the small gear}} = \frac{84}{14} = 6$$

**Written: 6:1**

Since the driven gear turns faster than the driver gear, the gear train is geared up.

**Gearing up** will increase the output speed but the output force is reduced (by a factor of 1/6 in this example).



## Slowing Down

A small driver gear turning a large driven gear slows the turning speed of the axle attached to the driven gear.

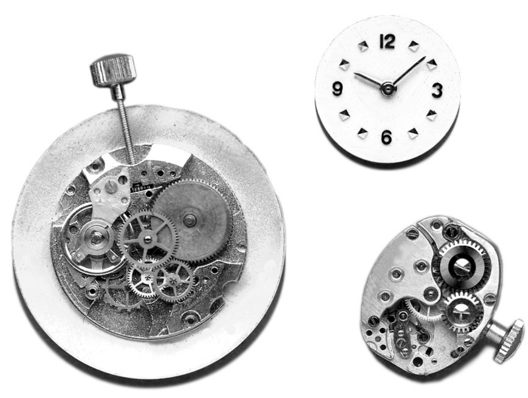
For example: A 14-tooth driver gear will make 6 complete turns for every 1 turn made by an 84-tooth driven gear. The Mechanical Advantage of this gear train is 6. The gear ratio is 6:1 but since the driven gear turns slower, this gear train is **geared down**.

Gearing down will decrease the speed of rotation, but increase the output force.

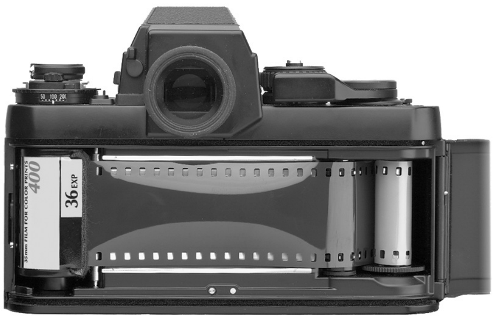
**REMEMBER:** When driving a car, you shift **UP** through the gears (1st, 2nd, 3rd, 4th) to go **faster** and shift **DOWN** through the gears (4th, 3rd, 2nd, 1st) to go **slower.**

## Types of Gears

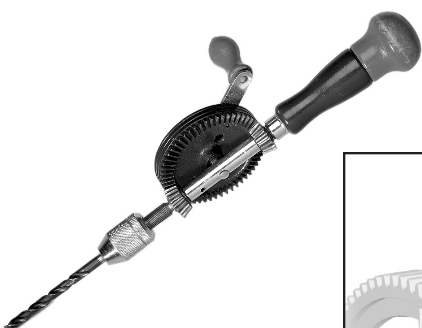
**Spur Gears:**
These gears lie in the same plane and turn in opposite directions when meshed. Different sized spur gears turn at different speeds and with different amounts of force.

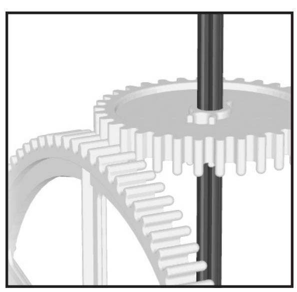


**Sprocket Gears:**
A special type of spur gear consisting of two gears on the same plane, set apart from each other and linked by a chain. Sprocket gears turn in the same direction. Different size sprocket gears turn at different speeds and with different amounts of force. If they are the same size they turn at the same speed and with the same force.



**Crown Gears:**
These gears lie in planes at right angles to each other. Different sized crown gears turn at different speeds and with different amounts of force.





**Rack and Pinion Gears:**
These gears consist of a toothed bar and a toothed wheel.
Rack and pinion gears change circular motion into linear motion.

**Worm Gears:**
These gears consist of a spiral edged cylinder called the worm and a toothed wheel called the worm gear. A worm and its worm gear turn in different directions, at different speeds and with different amounts of force. The worm gear turns more slowly than the worm. Worm gears generally slow down motion.

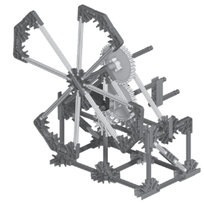
## Useful Web Site

http://science.howstuffworks.com/gear.htm

Don't be deterred by the first paragraph, which you may feel is too difficult for your students – if you continue through the site and follow some of the links you will discover some very helpful animations.

# THE CRANK FAN:

## An example of the use of a spur gear system



## OBJECTIVES

### Students will:

1. Understand and describe the transfer of motion through a spur gear system.
2. Investigate the relationship between gear size, speed of rotation, and force.

## MATERIALS

### Each student group will need:

– Building Instructions Booklet and K'NEX parts
– Masking tape
– Dot stickers (optional)
– Student Journals

### You will need:

– Pictures and examples of different spur gear systems. (Suggestions: music box; electric fan; hand-held can opener; gear operated toy.)
– K'NEX gears for students to examine before they begin the building activity. (Make sure each student has access to 2 gears.)
– 2 large rubber balls (optional.)
– Cardboard and Popsicle sticks (optional)

**NOTE:** As described below, this activity may take more than 45 minutes.

## PROCEDURE

### Introduction

- If this is the students' first experience with gears, you may want to demonstrate the transfer of energy from one object to another. Using two large rubber balls, have a student roll one ball into the other. Ask the students to describe their observations. Use the following questions to help them identify what took place:

  What did the first ball do to the second ball?

  ***The first ball pushed the second ball when the two balls came into contact.***

  When was the exact moment that the pushing took place?

  ***The first ball pushed the second ball.***

  What was transferred from one ball to the other?

  ***Motion, energy, force.***

- Distribute 2 gears to each group. Encourage them to think about how they would describe a gear and to explore how gears fit together.
- Begin the lesson by discussing and expanding what the students have discovered about their gears. You may choose to accept their operational definition for how the gears operate, or formalize the terms they use in describing the gears and how they fit together.

  ***Gears are wheels with teeth around their outer rim. The teeth of one gear fit between (mesh with) the teeth on the other gear.***

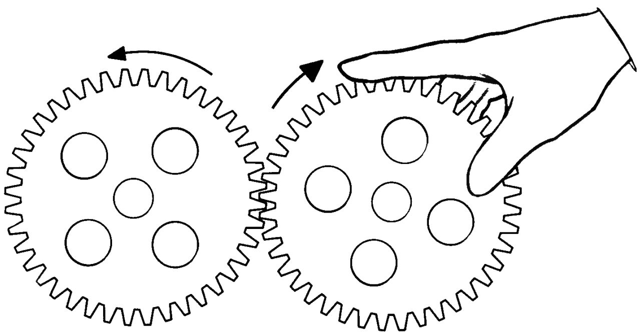
- Explain that gears are simple machines that transfer energy in the form of motion from one location to another. Use a child's gear toy or a gear train that you construct from cardboard to demonstrate what happens when you rotate one gear that is in contact with a second gear.

  ***Suggestion: Use circles of cardboard and carefully glue Popsicle sticks to them to represent gears. Make sure that the Popsicle sticks are evenly spaced around the circles. It is easier to make a pair of gears that are the same size than gears that have different numbers of teeth. Mount the gears to a larger piece of cardboard with pushpins, making sure that they mesh and rotate easily.***

- Distribute pieces of tape or dot stickers. Instruct students to place a small piece of tape (or dot sticker) on each of the two K'NEX gears they used earlier so they can observe the direction that the gears move. Ask students to lay the gears on a piece of paper on their desk and to mesh the gear teeth together. Ask one student to put a pencil point in the hole on each gear to hold them in place while the other student turns one gear.
- Ask the students how they are able to move only one gear and cause the second gear to also move.

  ***As one wheel turns, its teeth push against those on the other gear wheel. See diagram on next page.***

- Encourage the students to see how many gears they can put together into a gear train. They should sketch and label the direction of rotation of each gear.
- This is an excellent opportunity to introduce formal terms that the students should use during their experiments with gears. This activity lends itself to the introduction of **driver gear, driven (or follower) gear, and gear train.**



- Ask the students to describe which direction each of their gears turned.

  ***If the first gear wheel is turning in one direction, it will push the second gear wheel in the opposite direction.***

- Ask the students to think of other examples of gears used in their daily lives. Many students will identify the gears on bicycles. This will give you the opportunity to explain that there are several different types of gear systems and that the type used will depend on the job that needs to be done. For example, the gear system on a bicycle is different from the gear system in a can opener.
- Pass a hand-held can opener around the room. Allow the students time to explore the gear mechanism.
- Encourage the students to brainstorm a list of other objects that use gear systems. Record these on the board. Be prepared to show examples if the students are not aware of any gear systems.
- You may wish to introduce the concept of motion and use formal terms to describe the types of motions the students used in the previous activity. Some of the terms you may want to include are: **input motion** (the students' hands turning the first gear), **output motion** (the movement of the second gear caused by the input motion), **rotational motion** (turning about a point), **linear (straight-line) motion.** (Provide the students with an example of linear motion as a comparison to rotational motion.)

  ***Motion refers to an object's change of position over time in relation to a reference point.***

- Divide the class into groups made up of 2 to 3 students.

## BUILDING ACTIVITY

- Explain that they will build a model of a crank fan that uses a gear system to turn the fan blades. Direct their attention to the photo of an electric fan on page 28 of the Building Instructions Booklet or have an actual example for display in the classroom.
- Invite the students to build the model according to the Building Instructions Booklet (pages 28-29).

## INQUIRY ACTIVITY:
## How is motion transferred through a spur gear system?

Use the following guidelines and script to help the students explore the function of a spur gear system.

**Steps**

**1.** (a) When the models are completed, allow the students time to explore. Ask them to locate and identify the gears. They should watch the gear mechanism in operation as they turn the crank.

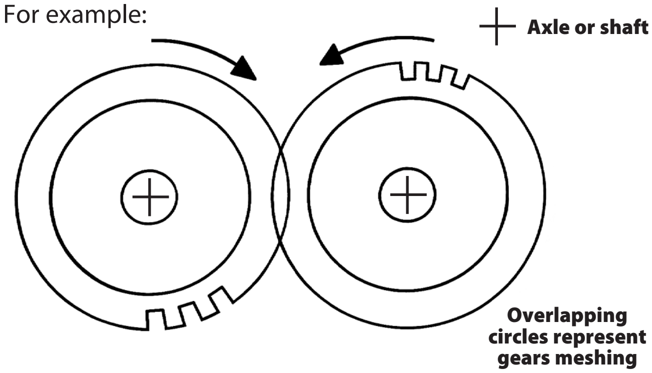
(b) Encourage the students to identify any additional simple machines with which they are familiar and that may be present in their fan models.

***If your class has already completed the wheel and axle investigations, this is an ideal opportunity to facilitate a quick review of this simple machine.***

(c) Ask the students to explain how the gear system turns the fan blades. Help students to see that the fan's gears fit together and that they are in line with one another. Remind students of their earlier investigation where they used the gears in line with each other as the gears lay flat on the table. Explain that in this arrangement, known as a spur gear system, the gears fit together, or mesh, along the same line or in the same plane. In this model the gears are arranged one above the other. You may have to ask students to turn the model on its side so they can see that the gears are in line with each other as they were in the previous activity.

**2.** (a) Ask the students to draw a diagram of the crank fan in their journals. The gears can be represented symbolically – there is no need for the students to attempt to draw every tooth in the gear wheels.

For example:



(b) Encourage the students to give names to the various parts of their model. You can then formalize these and ask them to label their diagram appropriately. Labeled parts will include:

**Crank, driver gear, driven gear, and fan blades.**

**3.** The students should respond in their journals to the following:

- Does the fan have moving parts? List the moving parts in your journal.

  ***Crank, driver gear, driven gear, fan blades.***

- Describe how the moving parts that you listed above are connected to each other.

  ***The crank is connected to the driver gear by an axle. The teeth on the driver gear mesh with the teeth on the driven gear, which is connected to the fan blades by an axle.***

- Describe the input motion - the motion they use when they operate the crank.

  ***The input motion is circular or rotational. They turn their hand in a circle.***

- Describe the motion of the gears.

  ***The gears turn or rotate.***

- Draw arrows on your diagram to show the direction each part moves as you operate the fan.

**4.** Ask the students to attach a small piece of masking tape to the edge of one fan blade and ask them to select a reference point so they can keep track of the fan blade as it rotates. Encourage them to turn the crank.

(a) Ask the students to turn the crank to make one rotation. Have them continue turning the crank but they should vary the speed at which it is turned.

Ask them how they can make the fan turn faster/slower.

***Students should observe that the speed of the fan was entirely dependent upon the speed at which the crank was turned.***

(b) Suggest that they mark the two gear wheels with either a dot sticker or with a pencil mark. The marks should be made at the point where the two gears mesh. Then ask them to make one slow turn of the crank. What do they notice?

***BOTH gears make one complete rotation with one turn of the crank.***

(c) Students should note in their journals the sizes of the two gears - driver and driven – used in the model.

***They are the same size.***

(d) Do they think there could be a relationship between the size of the gears and their findings to (b) above?

***The students should be helped to understand that these two gears, that are the same size and meshed together, rotate at the same speed even though they are on different axles.***

(e) Ask the students to turn the crank one additional turn, but this time, ask them to notice how far the fan blades travel. One student should count the number of times the blade with the masking tape passes the selected reference point, while the other should focus on making just one full turn with the crank.

***The fan blades also make one complete turn with one turn of the crank.***

(f) How easy/hard is it to turn the crank with this gear arrangement?

***NOTE: This will generate subjective responses, but will help the students make comparisons when they explore other gear arrangements for the model.***

(g) Ask them to summarize what their observations show concerning the distance the two gears and the fan blades turn with one rotation of the crank.

***Students should notice that all the moving parts rotate once with one turn of the crank.***

**NOTE:** We recommend that half of the groups work together for step 5 below. One group should build the model with the large gear as the driver, and the other group should build the version of the model with the small gear as the driver. Having both models available will make comparisons easier.

**5.** (a) Ask the students to speculate what they think will happen if they use:

(i) a large gear wheel to drive a small gear wheel and

(ii) a small gear wheel to drive a large gear wheel.

They should make a note of their responses in their journals.

(b) Encourage the students to discover if their predictions were correct by rebuilding their models using two gears that are different in size. They should use the diagrams on the right hand side of page 29 of the Building Instructions Booklet as a guide.

(c) Ask them to think of a way to compare the speed that the fan turns, with the speed of the crank when the big gear is attached to the crank and the small gear is attached to the fan blades.

***Use the technique adopted in step 4 - put a piece of masking tape on one fan blade and observe where it is before a turn of the crank and then notice how many times the tape passes that same point when the crank is turned one time.***

(d) How easy/hard is it to turn the crank with this arrangement compared to when the gears were the same size?

All their observations should be recorded in their journals.

***Students should observe that when the big gear drives the small gear, the fan turns more quickly than the crank: 1 turn of the crank results in approximately 6 turns of the fan blades. The***

***crank, however, is harder to turn than it was when the model had both gears the same size.***

(e) Students should then compare the speed at which the fan turns with the speed of the crank, when the small gear is attached to the crank axle and the big gear is attached to the fan blade's axle.

(f) How easy/hard is it to turn the crank with this arrangement, compared to when the gears were (i) the same size and, (ii) the large gear was the driver?

Observations should be recorded in their journals.

***Students should observe that when the small gear drives the big gear, the fan turns more slowly than the crank: it takes 6 turns of the crank for the fan blades to make 1 complete rotation. The crank, however, is easier to turn than in either of the other 2 gear arrangements.***

**6.** (a) Discuss their observations of gear systems using different sized gears.

(b) Ask the students if their observations support the prediction that they each wrote earlier. Encourage the students to support their conclusions using evidence from their investigations.

## Applying The Idea

- Review the findings of step 3 with the class:

Did the crank and the gear on its axle move at the same speed?

***They move at the same speed: one turn of the crank (wheel) causes the gear on the same axle to rotate once.***

Did you notice the same results when you used a smaller gear? A larger gear?

***Yes. Even when gears are a different size, if they are on the same axle they will rotate at the same speed.***

When you operated the fan using two gears that were the same size, which of these statements was true?

The driver gear turned faster than the driven gear.

The driven gear turned faster than the driver gear.

They both turned at the same speed.

***They turned at the same speed: one rotation of the driver gear turned the driven gear through one rotation.***

- Ask the class to summarize these findings about the fan with the same sized gears by completing the following sentences:

Gears that are on the same axle rotate at the

______________________________

***same speed***

Gears that mesh and are the same size rotate at the

______________________________

***same speed***

In this crank fan all the moving parts rotate at the

______________________________

***same speed***

because the driver gear and the driven gear are the

______________________________

***same size***

Ask the students to record the advantages and disadvantages of the 2 different gear systems they investigated in step 4.

***Turning the crank was easier when the small gear turned the large gear. However, the fan turned more slowly than the crank. Although the crank was harder to turn when the large gear turned the small gear, the fan blades turned much faster than the crank.***

Encourage the students to discuss situations where each gear system would be most useful. Encourage them to include "effort force," "driver gear," and "driven gear" in their responses.

***Answers will vary. Possible answer: A small gear turning a large gear would be most useful if the object that must be turned is heavy. Turning a large, heavy object would need less effort force when the driver gear is smaller than the driven gear.***

## Extending The Idea

(Suggested grade levels are indicated.)

**[Grades: 3-4]**

**1.** Suggest that the students search the Internet for additional information about gear systems. They could conduct a Google® search using the key word: "gear."

**[Grade: 5]**

**2.** (a) Remind the students that they used a crude measurement to compare the input and output speeds of the gear wheels when they completed steps 4(e), 5(c), and 5(e). Explain that what they discovered was a simple **Gear Ratio.**

(b) Explain that a more accurate approach is to compare results by counting the number of teeth on each gear wheel. Write the equation for the **Gear Ratio** on the blackboard, dry board, or overhead projector so that it is visible from any location in the classroom.

$$\textbf{Gear ratio} = \frac{\textbf{Number of teeth on large gear}}{\textbf{Number of teeth on small gear}}$$

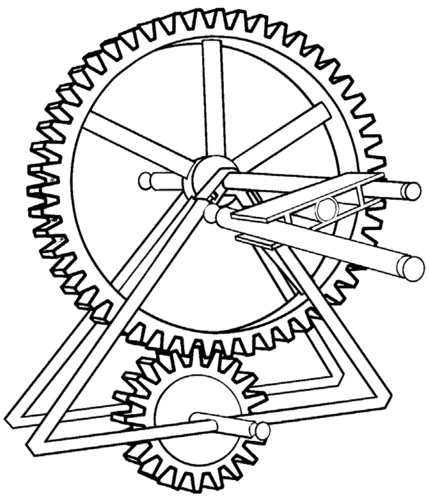
For example: a gear train with an 84 tooth gear and a 14 tooth gear produces an answer of 6. Written as a ratio that becomes 6:1.

If the output speed is faster than the input speed, the system is geard up. If the output speed is slower than the input speed, the system is geared down.

**[Grades: 3-5]**

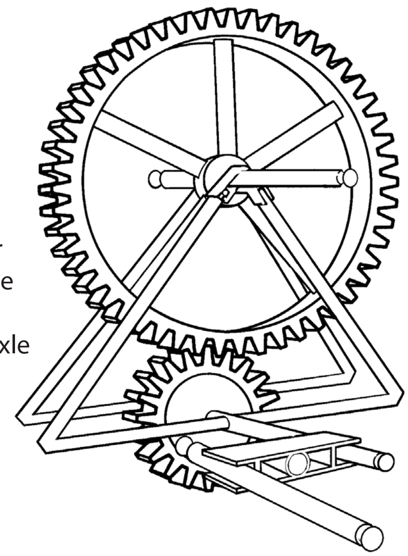
**3.** (a) Ask all the student groups to remove the fan blades from their crank fans and set them aside.

(b) Divide the groups so that half have crank fans in which the large gear is the driver gear and the small gear is the driven gear. The remaining groups should have crank fans in which the smaller gear is the driver gear and the larger gear is the driven gear. Students do not need to disassemble their fans. Simply have students attach the crank to the appropriate shaft. (See diagrams below.) In order to watch the speed of rotation of the second gear in the gear chain, students should attach a yellow connector to the end of that gear's axle. (This connector replaces the blades that, if used on the lower axle, will strike the tabletop unless the model is pushed to the very edge.)



**Set-up one:**
Crank on upper axle. Put the orange connector on the end of the lower axle.

**Set-up two:**
Crank on the lower axle. Put the orange connector on the end of the upper axle where the blades used to be.



**[Grade: 5]**

(c) Ask the students to determine the gear ratio and Mechanical Advantage of their crank fan. Students should write the gear ratio and MA in their journals and describe, in their own words, what the gear ratio and MA means in reference to their crank fan.

(d) Encourage the students to tell you what is gained by using this gear train. If students need clarification, ask them whether their fan turns quickly or slowly. You can then take this opportunity to help the students understand they cannot use a machine to gain both speed and force. They can gain speed at the expense of force or gain force at the expense of speed. If you decide to include this there is space provided in the chart below for students to record their findings.

**[Grade: 5]**

**4.** The groups should exchange fans and repeat step (d).

**[Grade: 5]**

**5.** Ask the students to organize their observations and conclusions regarding gears in a table or chart. (See Journal Check.) It may be helpful to provide a chart such as the one shown here.

| GEAR TRAIN SPEED | FAN SPEED VS. CRANK SPEED | GEAR RATIO (Geared Up/ Geared Down) | MECHANICAL ADVANTAGE |
|---|---|---|---|
| Gears are same size | | | |
| Large driver gear moving small driven gear | | | |
| Small driver gear moving large driven gear | | | |

[Grade 4-5]

6. Ask the students to brainstorm how they could change the design of the crank fan so that the crank and the fan turn in the same direction. If necessary, hint that they would have to add something to the mechanism. This will provide you with an opportunity to introduce the concept of the idler gear.

   Allow students time to test their ideas.

   ***The crank and fan would turn in the same direction if a third gear – an idler gear - were added to the gear train between the driver and driven gears.***

**JOURNAL CHECK:**

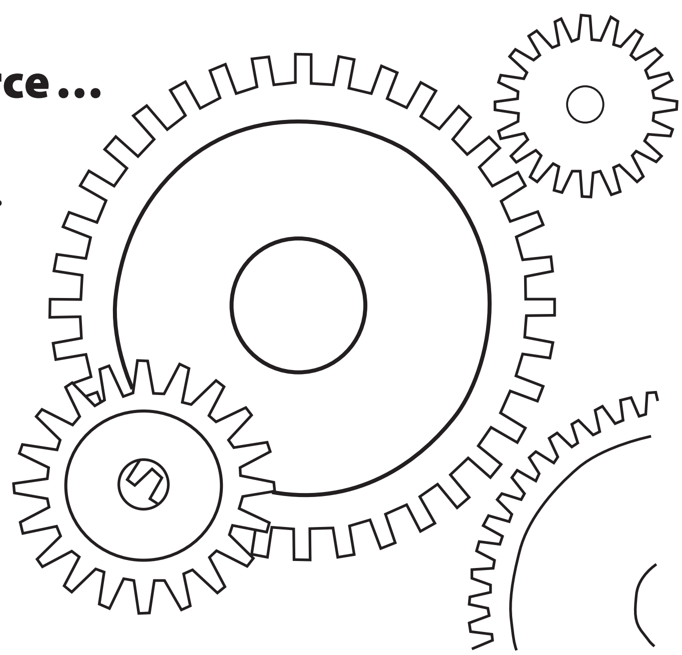
Students should keep individual journals to record their findings. The following are examples of the types of items that could appear in each student's journal:

- ✔ Diagram of crank fan including labels and arrows.
- ✔ Record of student observations.
- ✔ Predictions.
- ✔ Conclusions.
- ✔ A table such as the one shown below that summarizes their findings.

| GEAR TRAIN SPEED | FAN SPEED VS. CRANK SPEED | GEAR RATIO (Geared Up/ Geared Down) | MECHANICAL ADVANTAGE |
|---|---|---|---|
| Gears are same size | Gears are same size | 1:1<br>Neither | 1 |
| Large driver gear moving small driven gear | Fan speed is greater than crank speed | 6:1<br>Geared Up | 1/6 |
| Small driver gear moving large driven gear | Fan speed is slower than crank speed | 6:1<br>Geared Down | 6 |

# GEARS:

## Changing direction, speed, and force…



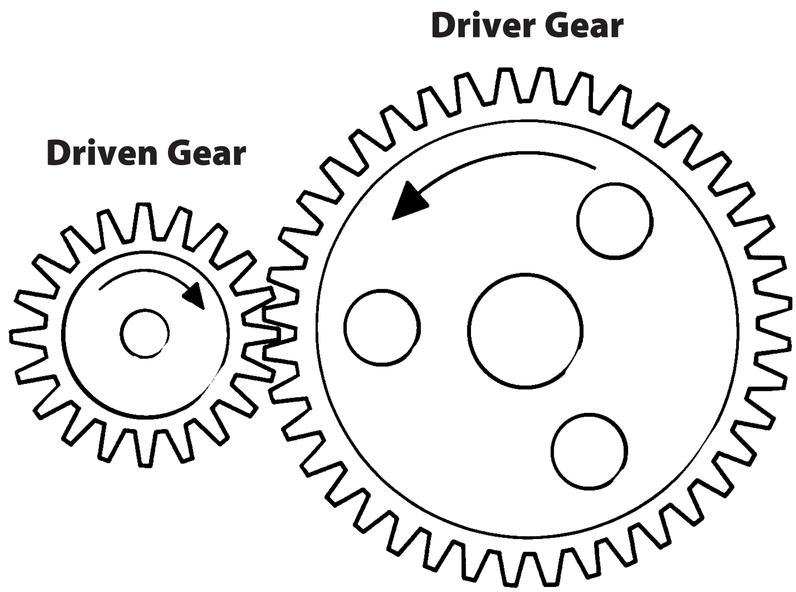
**A gear is a wheel with teeth along its outer rim.**

**Gears can:**

- **Change the direction in which something moves.**
- **Change the speed that something moves.**
- **Change the force needed to make something move.**

# GEARS:

## On the move...

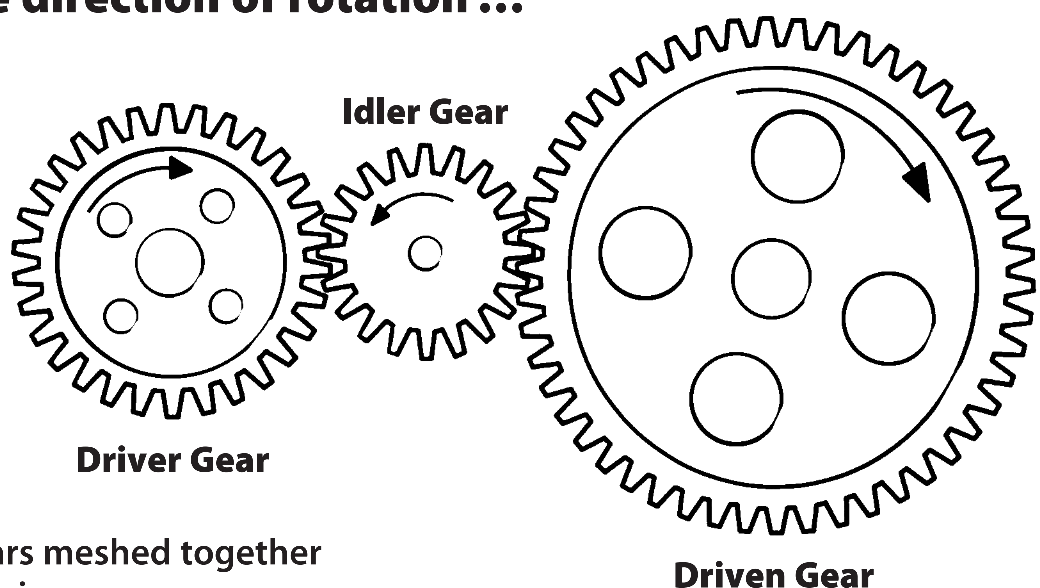



**DRIVER GEAR:** The gear to which the effort force is applied.

**DRIVEN GEAR:** The gear connected (meshed) to the driver gear.

# GEAR TRAINS:

## Changing the direction of rotation ...



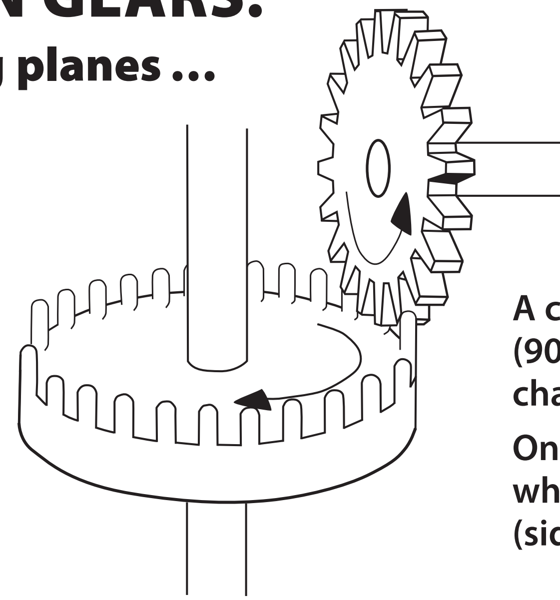

Two, or more, gears meshed together make up a gear train.

Meshed gears turn in opposite directions.

An idler gear makes the gears on either side of it turn in the same direction.

# CROWN GEARS:

## Changing planes …



A crown gear meshes at right angles (90-degrees) to another gear and changes the direction of motion.

One gear turns vertically (up and down), while the other turns horizontally (side to side).

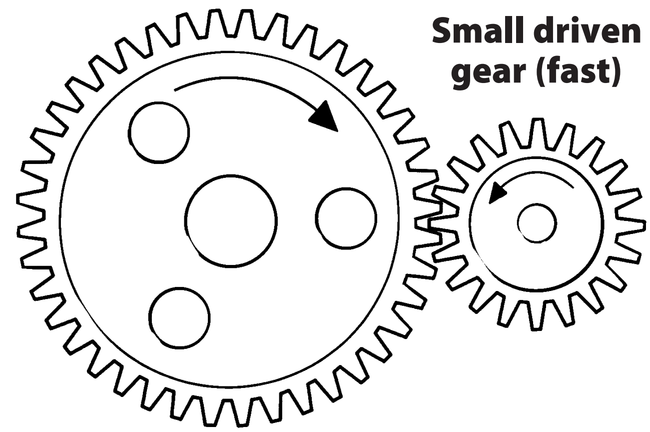
# GEARS:

## Changing speed and force…

**SPEEDING UP:**

A large driver gear makes a small driven gear turn faster.

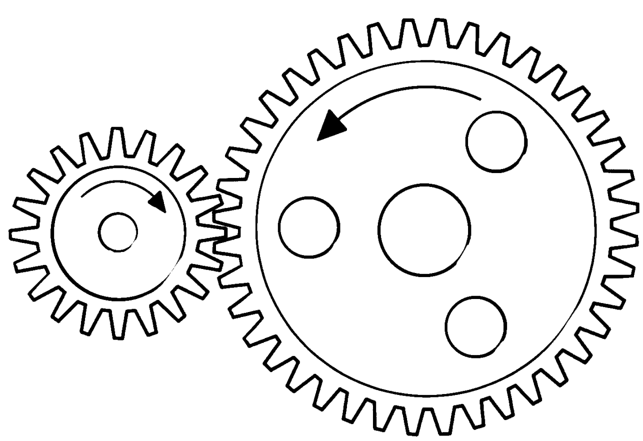
This increases turning speed, but reduces output force.




**SLOWING DOWN:**

A small driver gear makes a large driven gear turn more slowly.

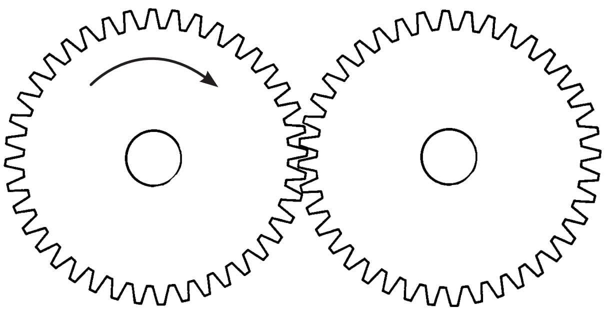
This reduces turning speed, but increases output force.



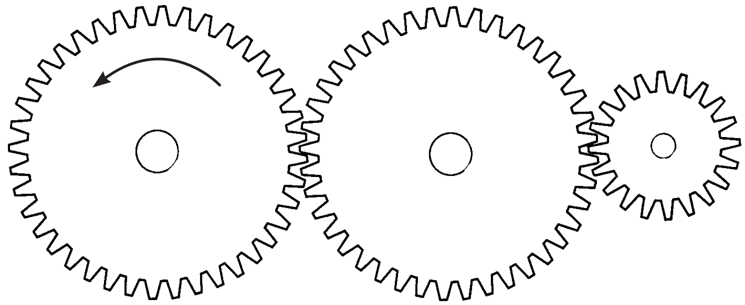
# GEARS:

## Try this . . .

**Which way will these gears turn?**



**(a)**



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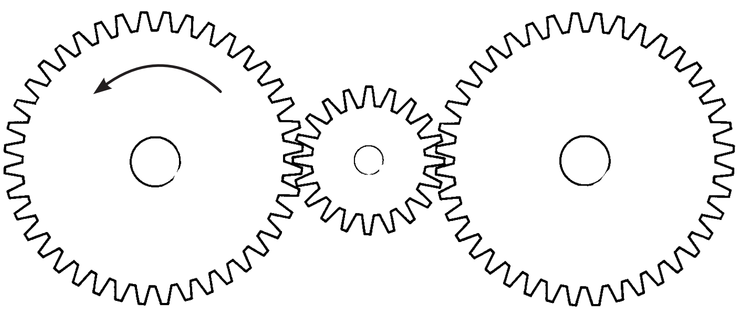

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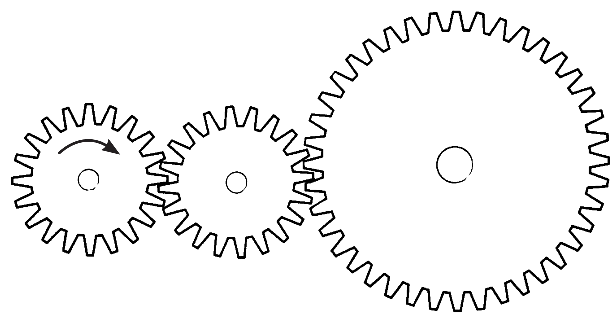
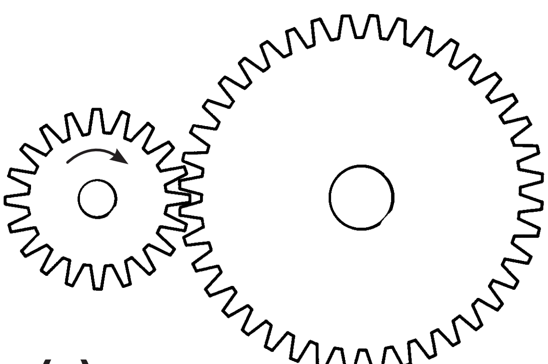
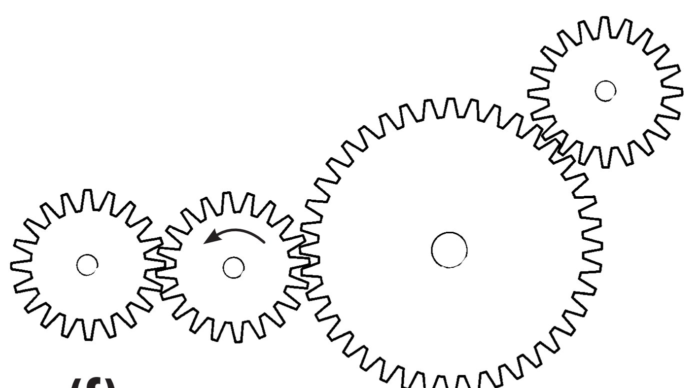


**(d)**



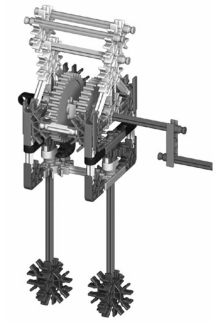
**(e)**



**(f)**

# THE EGGBEATER:

## An example of a crown gear system



## OBJECTIVES

### Students will:

1. Identify and diagram the various parts of the Eggbeater model.
2. Describe the transfer of energy in a crown gear system.
3. Investigate, demonstrate, and explain how a large gear driving a small gear in a crown gear system makes work easier.
4. Determine the mechanical advantage of the Eggbeater model both mathematically and experimentally.
5. Demonstrate that turning the large gear of a crown gear system causes the small gear to turn with greater speed.

## MATERIALS

### Each of students will need:

- Building Instructions Booklet and K'NEX parts
- Marker
- Masking tape
- Student Journals

### You will need:

- A pre-built Crank Fan model from the previous lesson.
- A real eggbeater for demonstration (optional)

## PROCEDURE

### Introduction

- Ask the students to describe how motion was transferred through the spur gear system found on the Crank Fans they built during the previous lesson.

  ***Force applied to one gear caused it to move and drive the second gear. Both the force and motion of the first gear was transferred to the second gear that turned the fan blades.***

- Using a Crank Fan model from the previous activity, review how a spur gear system can make work easier by changing the output speed or multiplying the output force. Remind students and help them to understand that they cannot use a machine to gain both speed and force. Explain that there is always a trade-off when they use a simple machine. They can gain speed at the expense of force when the machine is geared up or gain force at the expense of speed when the machine is geared down. Ask students to describe what is gained when a gear system uses the same sized gears in a spur gear system.

  ***Students should remember that when gears are the same size, neither speed nor force is gained. You can use this opportunity to explain that some machines use gears of the same size in order to change the direction of rotation.***

- Explain that a spur gear system is just one type of gear arrangement. Tell students that they will explore a different type of gear system that is found in an eggbeater.

- If you have a real eggbeater available, demonstrate how it works.

  ***You may wish to add some dish detergent to a clear bowl of water and use the eggbeater to make lots of bubbles.***

- Ask each student group to collect a large gear and a small gear from the Building Simple Machines Class Set.
  Have them lay the small gear flat on the table and then stand the large gear vertically (on edge) and mesh its teeth with those on the flat gear. Introduce this gear arrangement as a crown gear system. (The small gear is a spur gear as the teeth stick out from the edge of the gear. The large gear is a crown gear; it has teeth that extend up from the face of the gear perpendicular to the face of the gear.) If the students slowly and carefully turn the vertical gear, the flat gear will

also turn. If the students turn the flat gear in the same way, the vertical gear will turn. Ask students what they believe would be the benefit of using a crown gear system.

*The main benefit is to change the direction of rotation. As students investigate, they will find additional information about the crown gear system of the eggbeater.*

- At this point, ask students to count and record the number of teeth on the large and small gear. (They will need this information for a later activity when the model will already be constructed. It will be difficult for the students to make a correct count when the model is built.

  *Large gear = 34 teeth; small gear = 14 teeth*

## BUILDING ACTIVITY

- Distribute the Building Instructions Booklets and instruct each group of 2 – 3 students to collect the K'NEX pieces to build the **EGGBEATER**. (pages 30-31)
- The Eggbeater model will require that students pay particular attention to detail as they build. Monitor their progress as they work and ensure that they orient the large gears correctly to mesh with the smaller gears.

## INQUIRY ACTIVITY:
## How does this machine change the direction of the effort force?

**Steps:**

1. When the models are complete, allow the groups to explore and investigate. Encourage them to locate and identify the gear train. Ask them to identify which types of simple machines they find in this model.

   *Gear system (gear train) and a wheel and axle (crank/handle system). The gear train is made up of a crown gear system. Allow time for students to investigate the gears and their operation before discussing them with the class. Remind students that gears are actually wheel and axle simple machines.*

2. Instruct students to draw and label a diagram of the Eggbeater model in their journals. Ensure the following are identified on the diagrams: crank, driver gear, driven gear, beaters. Ask students to include arrows to show the direction of motion for each of the parts above. Remind students to maintain careful records of their observations throughout this lesson in their journals.

3. Help the students understand how their model works by asking them to investigate the following questions.

   - Where is the effort force applied?

     *The effort force is applied to the crank.*

   - What type of motion does the effort force produce?

     *Rotational.*

   - What type of motion is produced by beaters when an effort force is applied?

     *The motion of the beaters is also rotational.*

   - How are the motion of the crank and the motion of the beaters the same? Different?

     *They are both the same type of motion, rotational. They are different because the crank rotates in a vertical circle and the beaters rotate in a horizontal circle. These motions are also referred to as taking place in vertical and horizontal planes. You may wish to avoid these terms if the students have yet to study planes in their mathematics classes.*

   - Observe and describe the motion of each moving part on the model. Indicate whether the part rotates in a vertical or horizontal circle (plane).

     *Crank: vertical; large gear: vertical; small gear: horizontal; beaters: horizontal.*

   - Ask students to investigate and discuss the following with their group members.

     – How can you control the speed of the beaters?

       *By turning the crank at different speeds.*

     – Do the beaters turn at the same speed as the crank?

       *No! The beaters move faster.*

     – How many times faster do the beaters move than the crank? HINT: How many turns do the beaters make when the crank is turned one time?

       *The beaters move about 2 and one half times faster. Students will compute this value more precisely later in this lesson.*

     – Is it easier to turn the axle attached to the crank when the crank is in place or when the crank is removed?

       *It is easier when the crank is in place. The crank and the axle form a wheel and axle simple machine that multiplies the force applied to the crank.*

4. Ask the students whether the gear system in the Eggbeater model increases the speed of the beaters and/or changes the direction of the effort force applied to the crank.

   *The gear system changes both the speed of the beaters and the direction of their motion.*

## Applying the Idea

- The following list of questions will enable the students to clarify their understanding of concepts they have learned about the Eggbeater model and crown gear systems. The questions are intended to be used as part of a class discussion to focus student answers and to follow a logical path toward understanding. You may choose to make a copy of the questions for students to include in their journals or for use as an assessment instrument.
  - Where is the effort force applied to the Eggbeater model?
    ***To the crank.***
  - What type of motion is produced by the effort force?
    ***Rotational.***
  - The first gear in a gear system is called the driver gear. The axle attached to the crank turns the driver gear in the Eggbeater model transferring energy to the gear. What does the driver gear turn?
    ***The driver gear turns a second, small gear.***
  - What type of gear is the driver gear?
    ***Crown gear.***
  - The gear that the driver gear moves is called the driven gear. What type of gear is the driven gear?
    ***Spur gear.***
  - Is the driver gear vertical or horizontal when the Eggbeater model is held up?
    ***Vertical.***
  - Is the driven gear vertical or horizontal?
    ***Horizontal.***
  - How is energy transferred from the driver gear to the driven gear?
    ***The teeth of the two gears mesh together so the teeth on the driver push on the teeth of the driven gear transferring energy to the driven gear.***
  - How is energy transferred from the driven gear to the beaters of the Eggbeater model?
    ***The energy applied to the driven gear turns the axle (red rod) that is attached to the driven gear at one end and to the beaters at the other end. Thus the blades turn.***
  - What type of motion do the blades demonstrate?
    ***Rotational.***

## Extending the Idea

- Inform students that they are going to determine whether the gears on the Eggbeater model multiply the force of the blenders or the speed of the blenders. This information can be determined mathematically or experimentally. Students will calculate how many times the Eggbeater model multiplies force or speed.

- Introduce the formula to determine the mechanical advantage of a gear system with two gears.

  **Mechanical Advantage = MA**

  $$\frac{\textbf{Number of teeth on the driven gear}}{\textbf{Number of teeth on the driver gear}} = \textbf{MA}$$

  - Remind students that they recorded the number of teeth on the two gears earlier in the lesson.
  - Ask students to calculate and record the MA of the gear system.
    ***0.4 is the MA. Remember, there are no units for MA.***
  - Once the students have completed their calculations, help them determine what this value means.
    ***A value for the MA that is less than 1.0 indicates that the force that drives the beaters is reduced by more than half. For example, if a force of 10N was applied to the large gear, the beaters would spin with a force of only 4N (0.4 times the applied force of 10N.)***
  - Explain to students that the loss in force is balanced by the fact that the gears multiply the speed of the beaters. Ask them if they believe the beaters spin faster than they turn the crank of the Eggbeater model. Encourage them to test their model to see if the beaters spin faster.
  - Ask the students if they can find a way to see how fast the beaters spin. Accept several ideas and list them on the board. Help the students to see one way to determine the speed of the beaters is to count how many times they spin when the crank is turned one full turn.
  - Provide students with small pieces of masking tape and ask them to see how many times one of the beaters spins when the crank is turned one time. (Students will soon realize that they need some sort of marker on the beater if they are going to get an accurate count. The masking tape acts as that marker. Students should repeat their count three times to verify results.)
    ***The beater will turn just less than 2 and ½ times for every turn of the crank. Thus, the speed of the beaters was multiplied almost 2 ½ times by the gear system in the Eggbeater model.***
  - Help students to realize that the reduction in the output force on the beaters resulted in the beaters spinning almost 2½ times faster than the crank.

**OPTIONAL EXTENSION**

If a real eggbeater is available, students can experimentally determine how many times faster the beaters on that eggbeater spin than the crank turns. Eggbeaters tested by the author spun from 5 to 5½ times faster than the crank.

## JOURNAL CHECK:

- ✔ Diagram of the Eggbeater model with labels and directional arrows.
- ✔ Record of student observations and answers to questions asked of students.
- ✔ Mathematical calculation of mechanical advantage.
- ✔ Experimental calculation of how many times the crown gear system multiplied the speed of the beaters.