Machines That Help

Draft 2.0

Learning by Design™ Project

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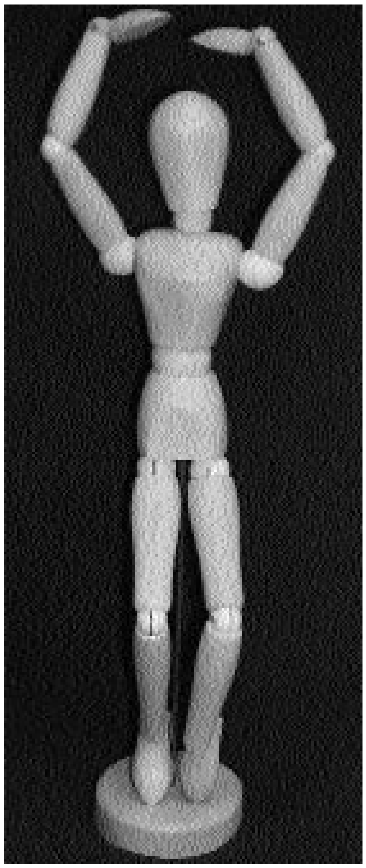
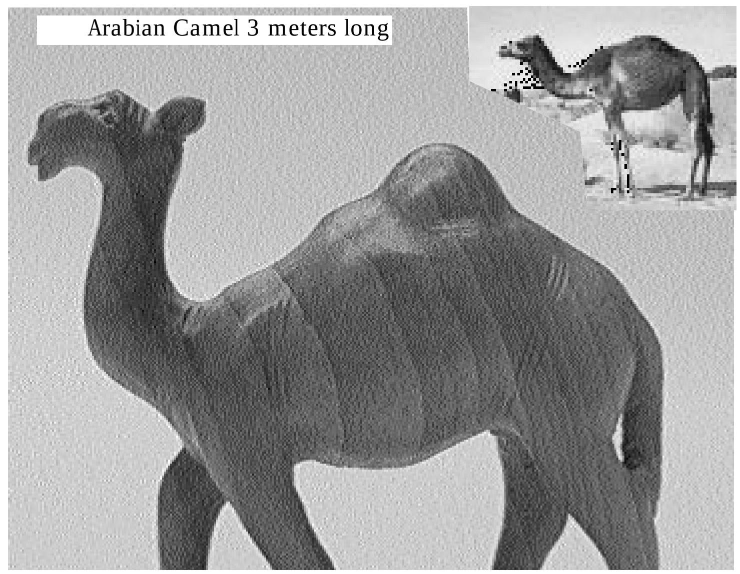
Extra Mile

What Is

People like to collect things. Some people collect dolls, autographed baseballs, old record albums, or “gag devices” that scare and surprise others. Some people specialize in collecting miniatures: copies of real things only much smaller. They can be alive or not: tiny cottages made of ceramic, stuffed rabbits or even cuddly crabs, jewelry that looks like elephants or camels, or plastic statues of Elvis Presley. All are models that look like something, only they are much smaller than the original.

A model used by artists for sketching and drawing people. Notice how models are not perfect. How is the model is different from the ballet dancer? How does the the model help an artist?





How Models Help

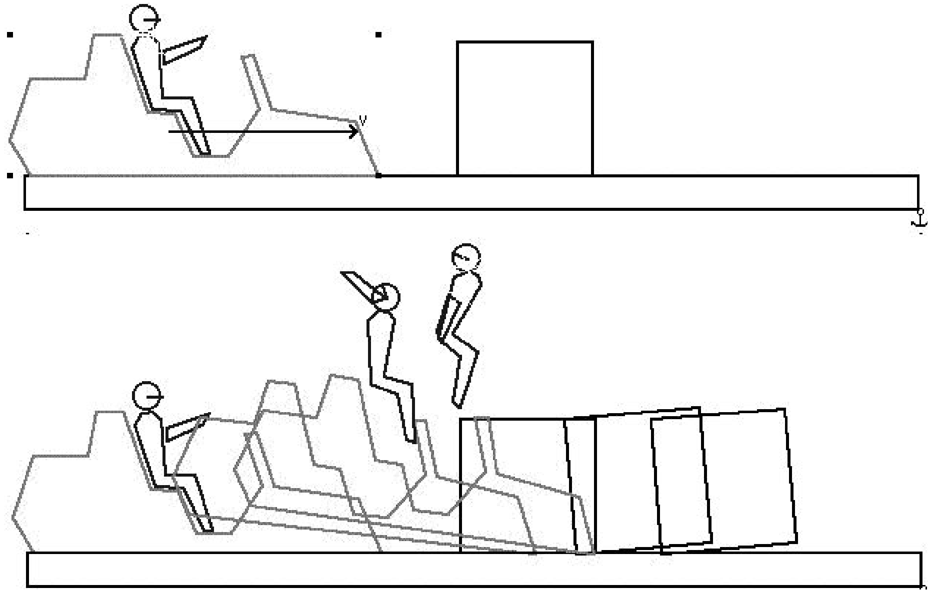
What are the benefits of having models of real things at a smaller scale? First, the model often is easier to “grasp”. Even in this age of inexpensive air travel, few people have traveled around the globe. Many more have seen a globe, and in part because of this, they know that the world is basically a sphere. Having looked at a globe, they may also have a sense of where the continents are (South America is closer to the South Pole, while North America is closer to the North Pole), and what the big oceans look like.

A Model?

Extra Mile

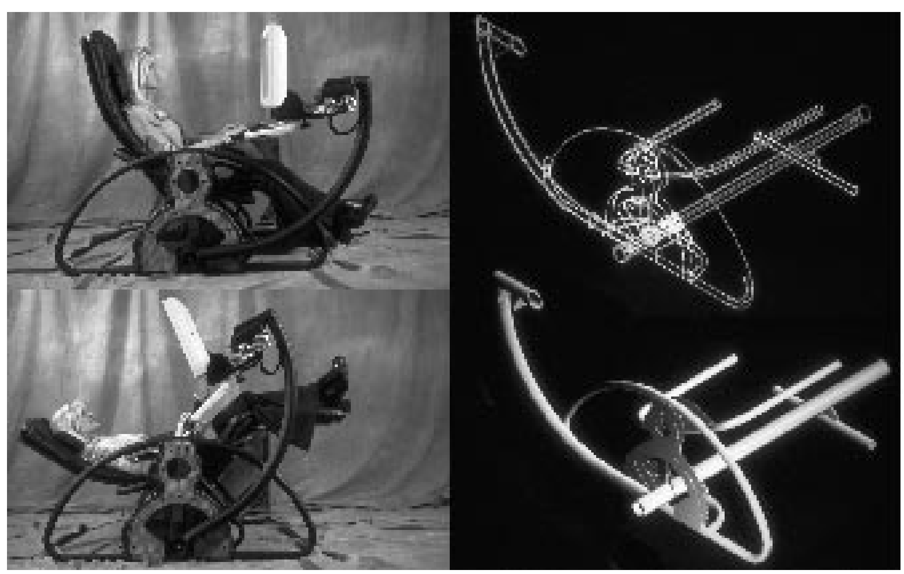
Models in Science

Scientists use all sorts of models in their work. Often, the models are based on math formulas which can be run on computers. The physicist can run simulations of a car crashing into a wall, or a cannon shooting a human cannon ball. These models help because the scientists don't have actually to crash the car or shoot the human cannon ball to know, approximately, what will happen. Models help scientists make predictions, but scientists know that models only make estimates and are not the real thing. They still need to do tests to make sure things work the way the model predicts it will.



Models in Design and Engineering

Before engineers who design automobiles build a full-sized prototype of a passenger car, they will build many smaller models to test their designs. The two big ways that models help these designers are: safety and money. If a car becomes hard to turn at a certain speed, this problem might be found out with the model. By testing the model first, test drivers take fewer risks. Designing with models also costs less time and money. Designers would spend a fraction of the time and money making 10 models than if they built the first idea they had as a full-sized car.



Homework

1. Compare this task with the model for Cliff. How realistic is the model of the Cliff assignment to the actual scenario? What kinds of differences would you expect if you built at full size?
2. Review the original challenge you have been asked to do: design something for people in need. How strong a link is there between it and the Cliff Challenge?

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Version 2.0

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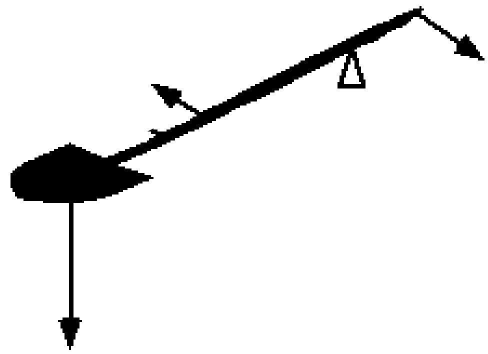
Homework for Making How-It Works Drawings

A. Look over the how-it-works drawing that show a long-handled shovel in use. What labels could be placed on the drawing of the shovel below to make the science clear in the how-it-works drawing? Devise your best explanation and labels to accompany the drawing to tell someone else how a long-handled shovel works and helps its user. Be sure to tell what kind of simple machine it is.



B. Make a how-it-works drawing and write an explanation for two of the following devices.

C. Make a "how-it-works" poster for explaining toasters to a child about the same age as Calvin in the cartoon (about 6-8 years old).

D. Write down guidelines for making effective how-it-works drawings. Share ideas with your classmates in a whiteboarding session. Your list may change as you get more experience using learn more about how-it-works drawings.

Final Presentation: Second Can-Lift Device

Review of What You Have Learned

In the last weeks, you have found out that products give an advantage involving using less or more force while traveling less or more distance. You have learned how to think like a scientist about simple machines. You have found out how to change and combine designs so that they provide just the kind of advantage you need. You have measured and calculated the mechanical advantage of a number of devices in different ways.

Now you're ready to present in class the fruits of your labors.

Demonstration of Your Device Lifting the Heavy Can

For your final presentations, you will first demonstrate your device to show whether it meets the minimum performance requirements for a Can-Lift device. It must raise a heavy can of food 20 cm in 15 seconds with limited force. The main constraint still applies -- you can only apply force through a single sewing thread at one time. That force can be multiplied by the device by as much as you need, depending on the design you came up with and built. You can attach the can to your device by any means available.

Presentation After Testing Your Device

After you've attempted to raise the heavy can with your device, you will give a talk about your design, which should include:

- a description of your design process, including your design decisions;
- the reasons for the design decisions you made;
- how-it-works drawings of various designs you've made and tested;
- the science ideas that supported your decisions; and
- data from the experiments you conducted.

Once finished with your presentation, you will be asked questions by your teacher and classmates. At least one question will focus on your team's design process. Be ready to talk about how your team did its designing using terms found in the Learning by Design™ (LBD™) Cycle.

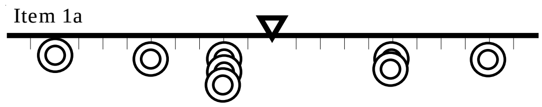
Another type of question will ask for evidence to support one or more of your team's most important design decisions. Data charts will help here.

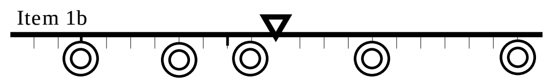
A third type of question will require your team, with only the aid of a calculator, to make a public calculation of the <u>mechanical advantage</u> of your device, using one of the approaches described in "Measuring & Figuring Out How Much Machines Help" on pages 54-55.

Review and Summary Section 2

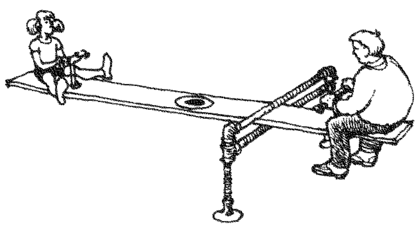
Balancing

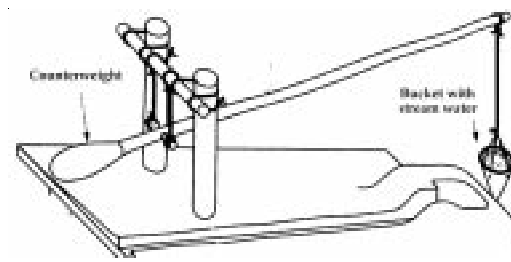
1. The two beams below have washers hanging at different spots on the beam. Each beam may or may not be in balance. Each hangs from the triangle, which acts as a pivot for the beam. Use numbers and your FxD = FxD formula to show whether each beam is or is not in balance. If not, use an arrow to show how moving one washer will bring the beam into balance. Redraw the new set-up for the beam, and use the same formula to show that it is in balance after the change.





2. Estimate by how much one side is more massive than the other in the following examples of first-class levers. Explain how you arrived at the number value of each estimate.





Definitions

Each definition question has two or more parts. Read both before answering them.

3a. Give your best definition of <u>mechanical advantage</u>.

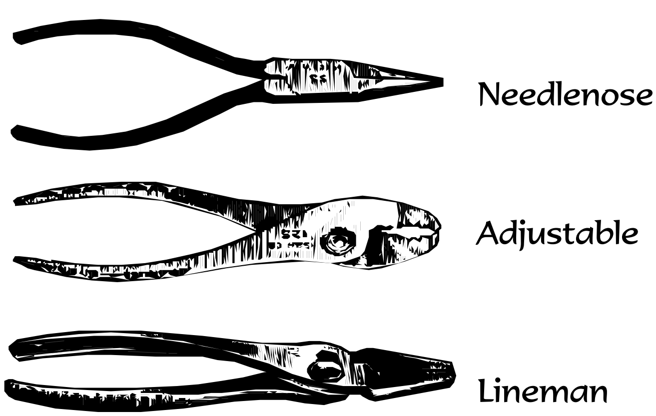
3b. What is a trade-off and how it is related to mechanical advantage.

3c. Use a how-it-works drawing and words to give an example that has yet to be done in class of a device that provides mechanical advantage.

4. Give your best definition of what <u>work</u> is, as it relates to machines.

5. Give your best definition of what a <u>lever arm</u> is, and given two examples of devices with one.

Do Some Pliers Help More Than Others?



6. (a) Which pair of pliers helps increase the force of the user the most when it is holding an object by the tip of its jaws. Explain why you think so. (Assume all pliers are the same length.)
(b) Which pair of pliers increases the force a user applies to the grips the least? Why?
(c) Make a how-it-works drawing for one of the pliers, and show the forces involved in using them.

Bigger, Higher, Faster

The Advantage of a Jack

7. Calculate the mechanical advantage (MA) for the screw jack that helps lift a car to the right. A user puts the top of the jack underneath something heavy,. like a car, and then pulls on the handle which turns the screw and moves the car up or down Show your work, and tell what method you used to figure out the mechanical advantage.

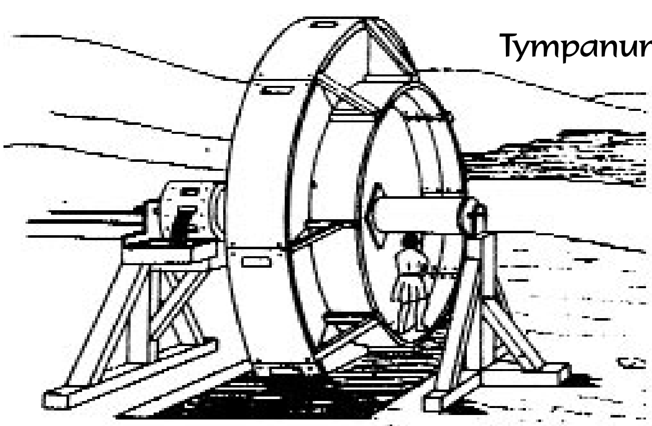
8. Calculate the mechanical advantage (MA) for the lever jack to the right. Show your work using numbers and a formula.

9. By doubling the length of the handles for the lever jack, what are the benefits and what are the trade-offs for the user?

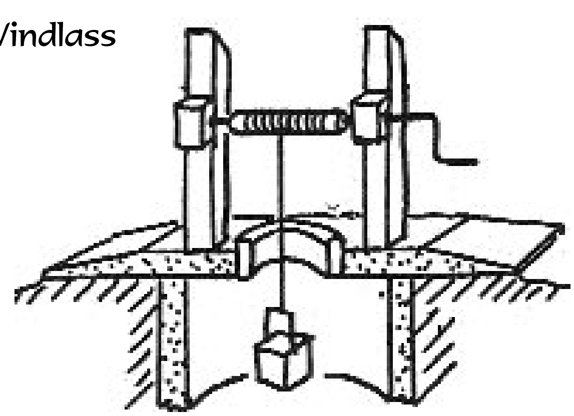
10. The press and the corkscrew each combine two simple machines to do their work. What are the machines within a machine for each?

A Look at Ancient Devices

11. The tympanum and windlass (pictured below) are two ways people in ancient times raised water. The tympanum is powered by the person walking inside the rim, who uses the largest muscles in the human body -- legs and back. The windlass is typically powered by the arms via a long crank handle. Which device or devices, if any, require the user to apply less force than the machine applies to the water? (In other words, which device, if any, has a mechanical advantage of more than 1.0?)



Tympanum



Windlass

Designing Machines That People Need

In the beginning of *Machines That Help*, you read that you would be asked to act as a consultant and design machines one of four groups of people who need help lifting heavy things:

(a) an elderly person at home;
(b) someone with limited strength;
(c) a teenager in the workplace; and
(d) people in a village with no electricity.

Now is the time you will apply what you have learned to helping a specific user from one of these four groups. Research and give a description of your chosen user, the lifting they need to do, and the device you would like to create for them. Include the following in your report:

- describe the user you are devising and the specifications of what they need help with;
- write about how the device works;
- make drawings, tell the scale of the sketch, and show the moving parts;
- tell what materials you recommend be used for making the real device;
- show forces acting on your device, and estimate how many times easier using the device is versus doing the task by hand (mechanical advantage -- tell method of calculation used);
- describe cases of similar products you've seen or used to what you are proposing; and,
- report on experiments you or others have conducted that support your design.

You may be asked to talk about this report in a Gallery Walk, so be ready with some interesting ideas. Show what you've learned, and do your best work. Good designing!

Machines That Help

Appendix

A Simple Machine Dictionary:

Axle -- Shaft that acts as a pivot around which a wheel or crank turns

Gear -- Flat, circular device fixed to an axle that meshes with other gears or chain and turns with a certain speed and twisting force (called torque).

Inclined Plane -- Flat surface placed at an angle to the ground. An angled road that allows easier travel that straight up a hill, though requiring a greater distance of travel.

Lever -- Simple machine that has an applied force and load at distances from a pivot and that provides mechanical advantage.

10 cm

Lever Arm -- Distance on a lever from the pivot to the applied force

Mechanical Advantage (MA) -- benefit that a machine gives a person that involves a trade-off. Usually based on the ratio of forces applied to the machine divided by the force output the machine provides. Example: If you apply 5 Newtons force on the handle of a nutcracker and the nut feels a force of 15 Newtons, then the device has a mechanical advantage of 15 Newtons / 5 Newtons = 3.

$$\text{MA} = \frac{\text{Force (Load)}}{\text{Force (Applied)}}$$

$$\text{MA} = \frac{\text{Distance (Applied Force)}}{\text{Distance (Load)}}$$

Technical Terms

Pivot (or Fulcrum) -- Point around which things rotate. Example: The pivot of a see-saw is where the board is attach to a support. The pivot where a

Pitch -- Angle of threads on a screw. Example: Coarse-pitched threads cause the screw to go further in one turn than fine-pitched threads. A steep pitch in a screw's threads is similar to a steep inclined plane. Fine threads are like a gently sloped inclined plane.

coarse thread

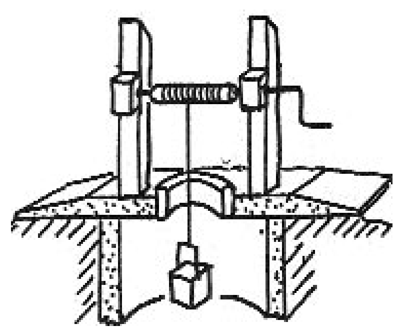
fine thread

Simple Machine -- A device that helps in doing work with different amount of force, over differing distances. Examples: three classes of levers; inclined planes and screws; wheels-and-axles and gears. Devices that combine one or more simple machines are called "complex machines".

Torque -- Sometimes when you apply a force, it makes an object move in a straight line. At other times, the force will make the device spin or rotate. The second kind of force, one that causes things to twist or spin, is called a torque. You apply a torque when you turn the volume dial of a CD player, use a wrench to loosen a bolt, or unscrew a lid from a jar. You get more torque by applying the same force at a greater from a nut than closer. A force that twists or goes in a circular motion is a torque. The bolt is experiencing the twisting force that is called torque.

Torque = Force x Distance (from Pivot)

Windlass -- Device for raising objects long distances using a rope, crank and cylinder around which the rope is wound. Mechanical advantage comes from sizing the crank and cylinder and drum so that the hand that does the cranking travels further but with less force than the drum which is hauling up the rope.



Work -- In physical science, work is distance that a force travels times the force itself. Just applying a force does guarantee that work is done -- there must be movement and force for there to be work. Example: You apply 2 Newtons to move a large apple up 2 meters to the top shelf of a refrigerator, and you will have done 4 Newton-meters of work.

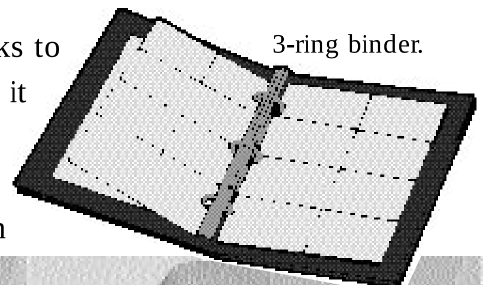
Work = Force x Distance (traveled)

Combining Plans To Get

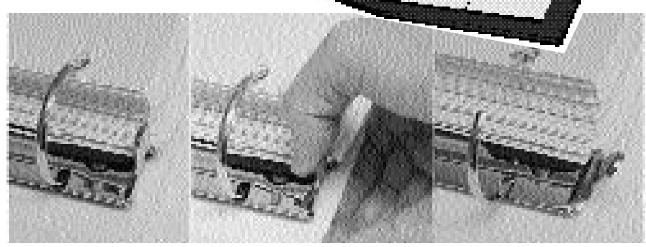
Two (of Many) Ways to Redesign a Device

Improving a design is a main goal of most designers, and your goal with the new Can-Lift Challenge. Here are two of the most common ways they go about doing it: (1) change an existing design and (2) combine existing ideas in new ways. Most designers do not come up with something completely new and different when they design. Such work is very well rewarded, but does not happen nearly as often as the two techniques mentioned above.

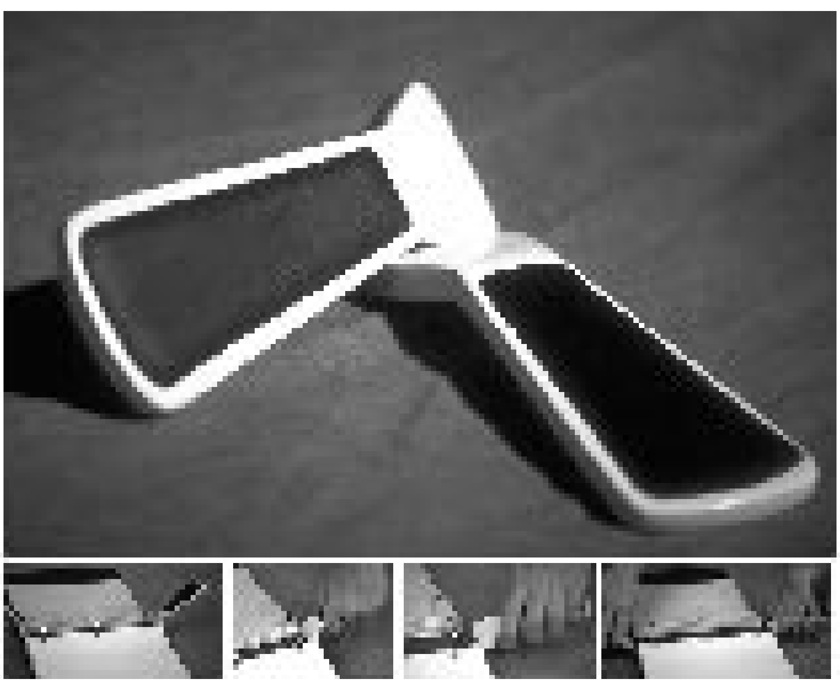
Method 1: Changing an Existing Design


3-ring binder.

Just about everyone has seen a three-ring binder. These are books to which you can add, subtract and reshuffle the order of the papers it holds. There is a small lever at the end of the metal binding which when moved causes the rings simultaneously to open, or you simply might pry open the rings. The paper in the binder can then be rearranged, put in, or removed from the notebook.


More than 30 Newtons of force is needed to open a standard 2-inch three-ring binder

Not everyone can use a three-ring binder, however. For some with weak hands or who lacks arm strength, opening one requires too much force. One solution to this need is shown below. The white plastic handles fit over the short lever built into most 3-ring binders and give added leverage to users. They need to apply much less force to move the mechanism that then opens up the rings.

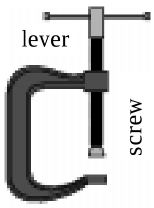

The removeable handles require less force for opening a 3-ring binder

As is true with all machines, there is a trade-off for the advantage the handles provide. The hand that moves the extension handle must travel much farther than it would when moving the original lever. This is an acceptable trade-off for those who otherwise could not use such a notebook.

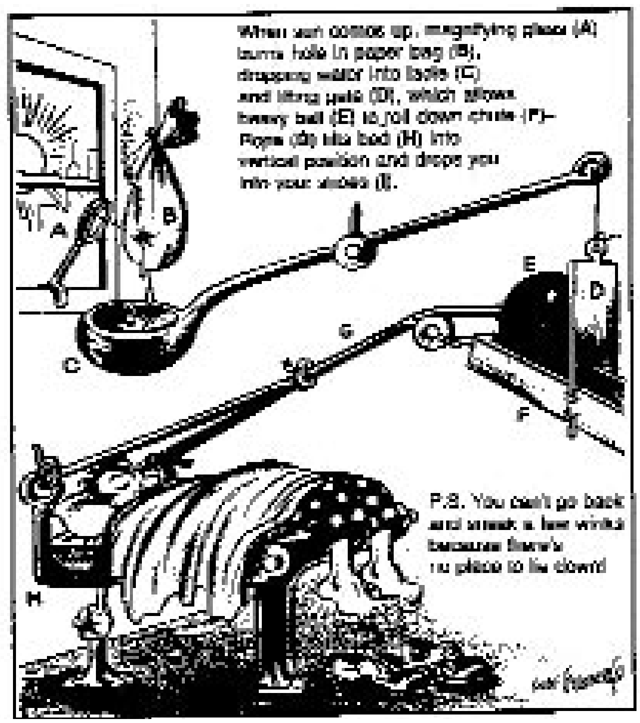
The Advantage You Need

Method 2: Combining Ideas

A second way of creating a better Can-Lift device is to combine ideas. This is especially true with simple machines, since they can be combined quite easily. In fact, there is a technical name given when ideas for two simple machines are combined -- such a device is called a complex machine.



Perhaps you used a C-clamp for cracking nuts. It is actually two simple machines -- a screw and a lever -- in one. And you can change either or both to get different performances from the device: including using different pitch in the screw's threads, or a longer or shorter arm for turning the C-clamp.

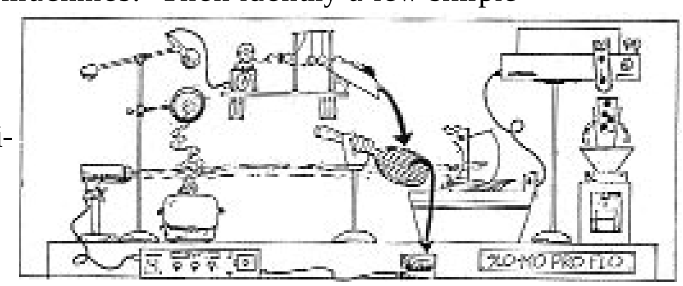


The cartoonist Rube Goldberg made famous devices that take the idea of combining ideas of simple machines to the extreme. This one-time engineer did this to put something that is funny to look at and imagine into operation. There are annual design competitions where students try to create a complicated device to do a simple tasks -- put a stamp on a letter, sharpen a pencil, toast bread, screw a light bulb into a socket, turn on a radio, or turn off an alarm clock.

Homework

1. You have seen cases of machines and devices thus far while doing Machines That Help. List 10 devices that are complex, not simple machines. Then identify a few simple machines that are contained in them.

2. Your Can-Lift Device can work in stages -- first you use a ramp, then a pulley, etc. Propose a multi-step Rube Goldberg-like device for lifting up a can of goods. This should be fun more than it is efficient. Try to make something more complicated than it needs to be, and funny to watch working.



Drawing by a student in a recent national Rube Goldberg design contest to pour water in 20 steps or more.

The Science of Simple Machines:

How Much Help Do Machines Bring?

By now, you should have a hands-on feeling that certain devices called simple machines can make doing certain tasks that require great force to be done with less force. By yourself, you can't lift a car, but with a jack, you can with moderate effort. You can't move a big rock, but with a long enough lever and the right pivot, you can.

Science gives the tools for telling how much such machines help. Armed with the right measurements and formulas, you can calculate whether you alone can pry the roots of a tree out of the ground, or whether you need one or two or three helpers. You can make predictions of how much a machine is able to help you. The scientific term for this help is <u>mechanical advantage</u>.

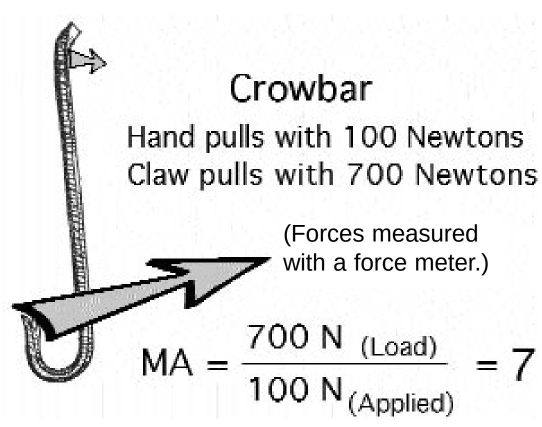
Here are two ways to express what that advantage is, followed by an explanation:

$$\text{Mechanical Advantage} = \frac{\text{Force}_{(Load)}}{\text{Force}_{(Applied)}} \qquad \text{Mechanical Advantage} = \frac{\text{Distance}_{(Applied)}}{\text{Distance}_{(Load)}}$$

If a device requires you to use less force than if you did it by hand, you have something that offers a mechanical advantage more than 1. If you put in 10 Newtons of force, and a car jack puts out 1000 Newtons of force, you get a MA = 100. If a child sitting on a seesaw weighs 200 Newtons (a little less than 50 pounds) and sits on the seesaw so that she lifts her father who weighs 800 Newtons (nearly 200 pounds), her use of the seesaw gives her a MA = 4. You can calculate MA using either the Force or Distance method. When scientists or engineers do this calculation, they choose the method that they can make the measurements more easily and accurately.

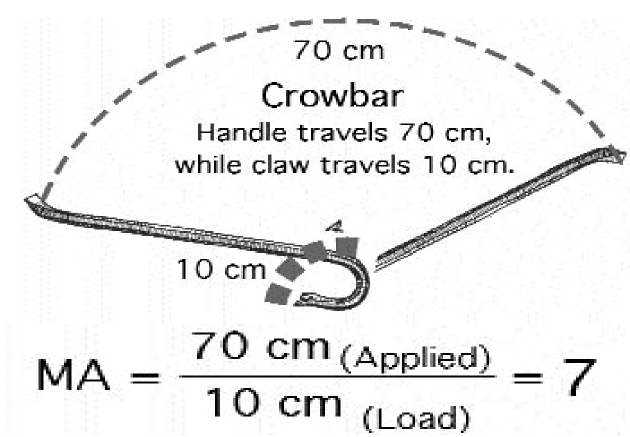
Here are the two methods, side by side, used to calculate the MA for the same crowbar. A crowbar is nothing more than a claw hammer that is stronger and has a longer lever arm to help users more.

Crowbar's MA - Force Method



The crowbar makes pulling things like nails easier, and so has an MA greater than 1.

Crowbar's MA - Distance Method



The hand that pulls the crowbar travels further than what the crowbar's claw raises.

Work & Mechanical Advantage

Work and Getting the Job Done

In everyday language, work is what you do to get things done. When people talk about work, they can mean things you do with your body or your mind. When scientists and engineers talk about work, they mean a very specific thing. Work for them is the force that is used to move an object *times* the distance the object travels.

Can you apply a force with your muscles, yet produce no work? Imagine pushing against a large rock wall. According to science's definition, no work is done, since you applied lots of force but the object didn't move. To do work, you need to move something a distance, while applying the force. The formula for figuring out how much work you do should be easy to remember:

$$\text{Work} = \text{Force} \times \text{Distance}$$

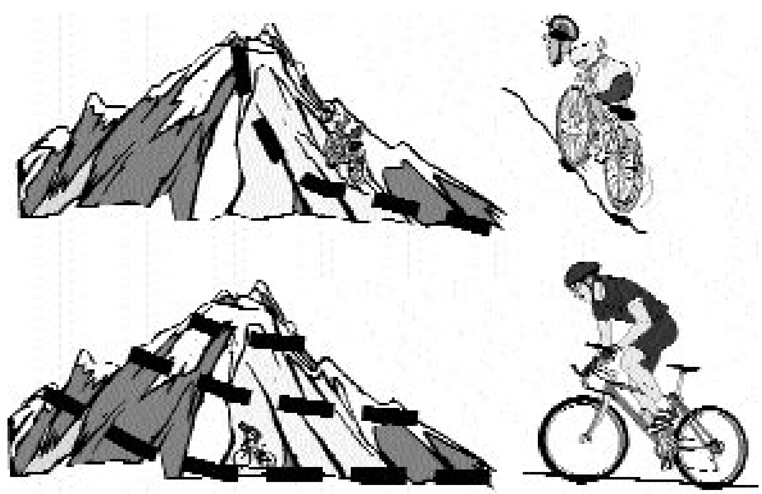
What increases the work you do? If you apply twice as much force lifting a heavier box than a lighter box, and you lift both the same distance, you do twice as much work with the heavier box. Also, if you lift a light box twice as far as another light box of the same weight, you do twice as much work.

Two Cases of Going Up Mountains

Let's say you want to move some luggage up a hill, and you have three ways to take it there. The first is to use a pulley to raise it directly up the hill. The second is to travel up a steep road, and the third is up a gently sloped road.

Given the idea of trade-offs and work, we know that in each of the three paths, the forces and distances balance each other out, and so the work in raising the object is the same in each case. The longest path demands the least force, but goes a long way; the shortest path, straight up, demands the greatest force over the least distance. If you forget about friction, science would say the Force *times* the Distance traveled will be equal. *Getting uphill requires the same amount of work, no matter which path you take.*

Let's look a similar example. A mountain biker has to choose between two trails to reach the top of a mountain. Does the pathway matter as to which one he should take? Sometimes, yes!! He might have limited time and needs to get up quickly, so the shorter, steep path is better. He might also want the easy way up, and have no concern for time. In that case, he'll choose the longer path. For science, however, no matter which path he takes, the biker does the same amount of work. The Force times the Distance is the same each way.



Whether you take the short-cut or the long winding road, you do the same amount of work getting up the hill.

Measuring & Figuring Out

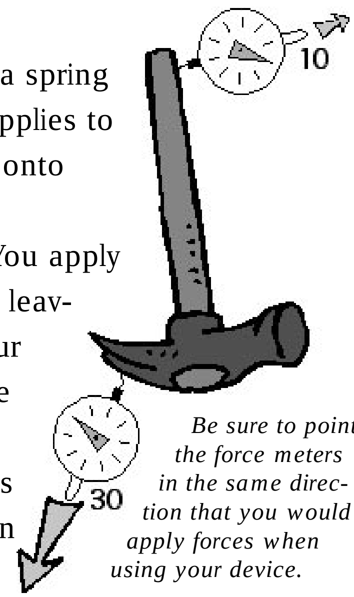
Figuring Out Mechanical Advantage

For your final Can-Lift presentation, you must figure out how much mechanical advantage (MA) your device provides. To do this, you need to make measurements and then use the formula you've just read about (page 52) to figure out the MA. Below are two basic techniques for determining what is a device's mechanical advantage. One measures forces; the second measures distances.

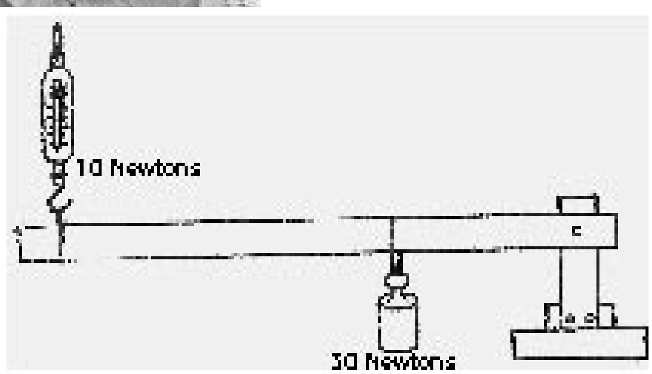
Force Method

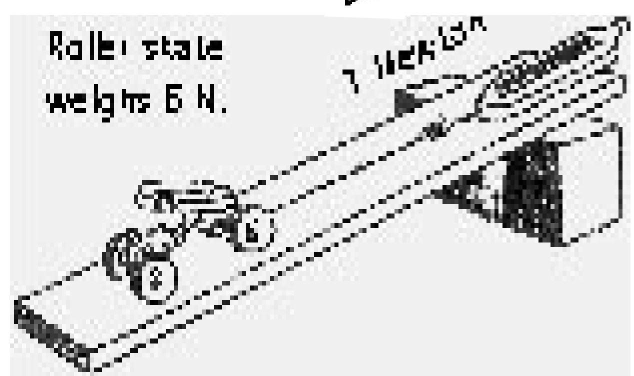
To do this method, you need an instrument that can measure forces – like a spring scale or force meter. You must take two readings: the force that the user applies to the device (Applied Force), and the Load or force that the machine applies onto something when doing its task.

Take the case of using a hammer to put out a nail. You apply force to the handle, and the load is the nail resisting leaving the wood. You can attach two springs where your hand and the nail apply forces. Pull the scales at the same time and take a reading. Repeat this process until you get readings you can rely on. The numbers should confirm what you feel: you apply less force on the handle than the hammer does on the nail.



Be sure to point the force meters in the same direction that you would apply forces when using your device.





The above pictures show the force method in action. Notice that you do not have to measure any distances in this method, only forces. Can you figure out the the mechanical advantage of the lever lifting the 30 N load and raising the 6 N roller skate up the inclined plane using the force method?

The big question in figuring out MA is this: which value goes on top and which goes on the bottom in the formula? Hint: If the machine applied more force than you did (and you traveled more distance than the Load did), then you got some help with the force and the MA is greater than 1. If the machine apply less force acting on the Load (and went a greater distance) than you did using the device, then the MA is less than 1. Once you know this, you can insert numbers into the MA equation. If the MA must be greater than one, put the larger number in the numerator. If the MA must be less than one, put the larger number in the bottom of the fraction, or the denominator.

So what is the mechanical advantage of the hammer prying out the nail? MA = 30 / 10 = 3.

How Much Machines Help

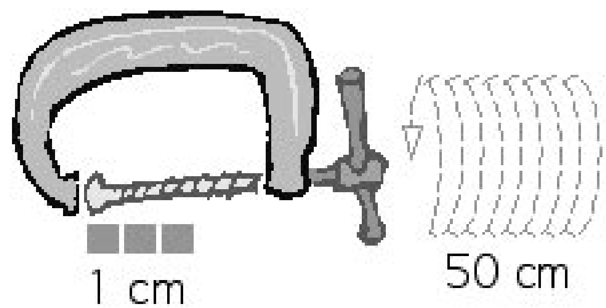
Distance-Traveled Method

Sometimes measuring forces can be difficult. How can you measure the force a person uses in turning a round doorknob, for instance? You might have a hard time attaching a spring-scale to the handle, and an even harder time attaching one to where the handle is connected inside the door.

Another way to figure out mechanical advantage is to measure distances that the Applied Force and Load travel. To do this, you first need to identify the exact place where the Applied Force is located on the device. Then you must do the same with the Load. Then, observe the device closely. Note the exact path that these forces travel when the device is used. Do you remember the dotted lines of the "how-it-works" drawings? Make a sketch of your device and put in your own dotted lines to show where and how far each force moved. Then measure the distances traveled for these two forces when the device is used.

Mechanical Advantage (MA) can equal either the ratio of forces at work in a device, OR the ratio of distances traveled by those forces. But which distance value goes on top of the MA formula, and which goes on the bottom (does the dividing)? Here is an easy way to figure this out, which is based on your experience of the device:

If the place where you applied force travels further where the device carries its load, then the MA is greater than 1. If you travel less distance than the Load does, then the MA is less than 1. (You can also use the hint from the bottom of the previous page to figure out which number goes where.)



The hand that turns the arm of the C-clamp travels much further than vise part that grips an object. Is the Mechanical Advantage greater or less than 1?

So let's set up the equation and figure out the MA for the C-clamp shown to the right. First, you need to estimate whether the clamp has an MA of more or less than 1. Since your hand travels 50 cm turning the handle, and the jaws only move 1 cm, you know you are getting some help with the force, and your MA is more than 1. So, putting the numbers to the MA equation so that is will equal more than one means that the bigger number (50) goes in the numerator and the smaller number goes in the denominator). MA = 50 / 1 = 50.

Homework 1. Use the distance method to determine the MA of your current design. Show your measurements along with a drawing of your device and way you figured it out with numbers.

2. Use the distance method to figure out the MA of one other device at home. Report your results.

3. Which class of levers (first-, second-, or third-class) has a MA less than 1? Which class is always greater than 1? Which one depends on location?

4. A C-clamp contains two simple machines in its design. Imagine that the lever handle offers an advantage of 2 and the screw an advantage of 10. Do you think the total mechanical advantage is the sum (10 + 2 = 12) or the product (10 x 2 = 20) of each advantage?

Case Study of Your Final Can-Lift Machine

In this writing assignment, you will write up a complete case study of the history of your group's design of your best "Can-Lift" device. Each case study should include the following parts:

- • the way it works -- describe the problem you were solving, how your device works, and the simple machines it contains (review the "Product Specifications" and "My Whiteboarding Summary" pages of your Design Diary for this);
- • product specifications -- use number values when possible to describe constraints that your design followed (review the "Product Specifications" pages of your Design Diary for this);
- • how-it-works drawing -- provide a sketch (or an optional photograph of the actual device) that shows forces and distances traveled by the device's applied force and load;
- • history of design ideas -- what designs did you consider first, next and finally (review the "Testing My Design", "Idea Generation" and "My Whiteboarding Summary" pages for this);
- • science ideas used -- describe the science you learned, and how this influenced you designs (review the "Lessons Learned" pages of your Design Diary to gather your ideas for this);
- • experimental data -- observations and measurement of the product in use (review the "My Experiments" and "Testing My Design" pages of your Design Diary for this);
- • calculations -- your calculations of how much mechanical advantage the device provides;
- • inspirations -- description of other products that inspired your design;
- • similar devices -- make comparisons with devices that are similar either in form or function
- • other influences -- refer to others' reports, gallery walks, or interviews or focus group meetings you held that made a difference in your design.

You will find that the writing you have done in your Design Diaries will pay off handsomely in making your essay richer in details and specific examples. Include data from experiments to show the reasons for the design decisions you made.

You may want to use the five-paragraph essay format that you practice writing in language arts in doing this assignment. What you write may be included in a classwide Case Library that will be read by other students, including those who in later years will take this course. Make their reading easier by writing clearly and using drawings whenever possible so that in later years others will not need to ask you questions about what you did.

Designing & Rebuilding Your First Can-Lift Device

Your work for Section 1 in *Machines That Help* is coming to a close. Here is a summary of what is in store before its end, which you can find in more detail on page 13.

> **10. Do Second Attempt at the First Can-Lift Challenge --** After collecting ideas from your walks and writing cases that include illustrations, you may have a planning session to improve and build your First Can-Lift device.
>
> **11. Gallery Walk and Whiteboarding --** After your second design session, you may do a pin-up or gallery walk and a whiteboarding session to talk about new design ideas.
>
> **12. Review and Summing Up --** You'll do questions at the end of the unit to help you see what you understand thus far, and may write in the "Lessons Learned" Diary page.

A first design plan is rarely the final design plan -- at least for most designers. Expect your design ideas to change as you understand the problem better, learn more approaches to solving it, and find out how these device can help, even with trade-offs. In Section 2, you will even figure out how much your devices help, which will help you in deciding which ideas to keep and which to throw away in your final Can-Lift device.

For right now, you might want to meet with your team to review ideas you've recently learned, cases you've recently read, and experiments with their design rules-of-thumb you and others have shared. Which approaches that you've had your eye on look promising?

Here are a few goals here to accomplish while doing this work:

a. get the device to lift a medium-sized can with a single thread;

b. follow <u>all</u> rules for the challenge (are you only using a single strand of thread?);

c. record the different designs you come up with, even if you don't use them, and tell what you like and don't like about each of them;

d. remember that you will be faced with lifting a heavier can in Section 2 with the same cotton thread you must use for this section; and,

e. explore some new approach even if you think in the end you might not stay with the exact idea.

Be ready to share any new design rules-of-thumb you devise in your next pin-up or gallery walk session. Remember that having a good explanation for *why something doesn't work* is just as good for your individual and team grade as coming up with the most ingenious design.

Review and Summary Section 1:

Trade-offs for the Moving Van's Ramp

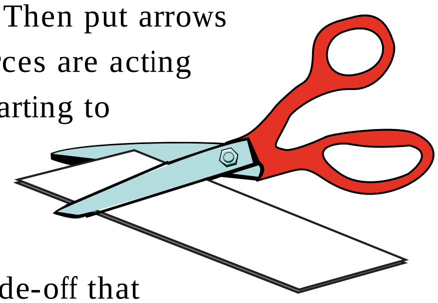
1. It is harder to carry a weight up a short, steep ramp than a long one with gentle slope, but it is easier than raising a weight straight up. What trade-off must you accept when using a ramp to make the job easier?

Levers That Help

2. Make a how-it-works drawing of the a 1st, 2nd and 3rd class lever, each on a separate sheet of paper. Be sure to label all parts and tell what forces are at work when the devices are in use.

How Scissors Work

3. Make a sketch of a pair of scissors. Then put arrows to show where and in what direction forces are acting on the scissors when a person is just starting to cut paper with them (when the paper is close to the pivot of the scissors). Explain how this machine gives its user an advantage in doing the task, and trade-off that a person would experience using the device.

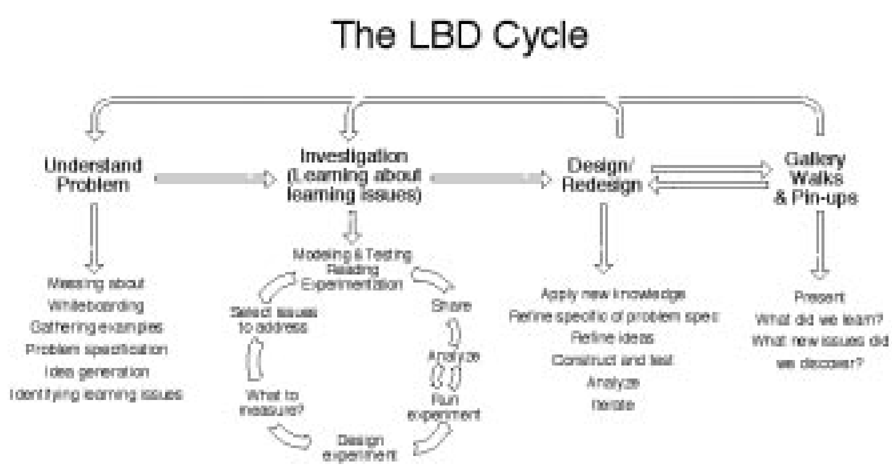


Thinking About Your Design Process

4. Look at the picture of the LBD™ Cycle to the right.

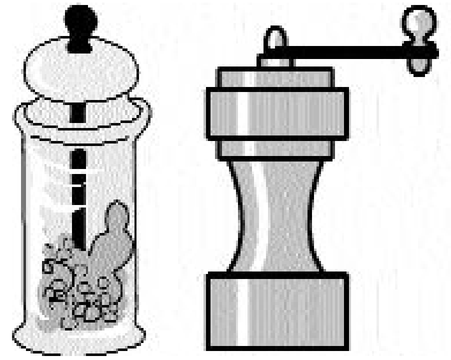
(a) Tell which steps (up to three) were the most important for you in doing your Can-Lift device. Tell why these were important.

(b) You've just finished redesigning your Can-Lift device. What steps in the LBD™ Cycle were key second time through, and why?



Exploring Machines That Help

Which Pepper Grinder Needs Less Force to Use?



5. The two devices to the right grind whole pepper, which is held in the cylinder in the middle. In each case, the top of the device turns, which spins the grinder near the bottom holding the pepper. When used properly, finely-ground pepper comes out of the bottom of the device.
The difference between the two grinders is how the top is turned by the user. In one case, the clear plastic top is grabbed and twisted, and in the second case, a lever handle is turned.
(a) Which grinder would be easier to turn? Why?
(b) Which of the four devices for the First Can-Lift Challenge is the grinder to the right most like?

How To Use a Wrench to Get the Water to Fight a Fire

6. The fireman is using a large wrench to turn a nut to get the water to flow out of the fire hydrant. Which of the following things could the fireman do to gain more advantage from the wrench?

a. Move his hands along the wrench so that they are closer to the hydrant.
b. Move his hands along the wrench so that they are further away from the hydrant.
c. Apply more force with his muscles but without moving his hands.
d. What kind of simple machine is this wrench?

How Food Tongs Work

7. Below is a person using tongs to handle food as it is being prepared. On a separate sheet of paper, draw a how-it-works drawing of the tongs, using arrows to show the various forces on it. Use arrow length, direction, and location in the appropriate ways. Finally, tell upon what type of simple machine the tongs are based.

Forces on a Clothes Pin

8. Make and label a how-it-works drawing for a clothes pin. Be sure to include the following:
A. Identify the Pivot, Applied Force, and Load when the pin holds clothes, and when opened by hand.
B. In each case, tell if the force is greater where the wire presses against the wood or where the Load is.
C. Tell what type of simple machine a clothes pin is.

Machines That Help
Section 2
Bigger, Higher, Faster

Appendix page 61

For your Second and Final "Can-Lift" device, you must lift a heavier can of juice up a distance of 20 cm in 15 seconds.

You will learn how to figure out how much your device helps, write a case history of how you developed your device, using facts and figures from your Design Diary. Finally, you will make recommendations for solving Cliff's (or someone else's) problem.

Upping the Ante: The

Section 2's Can-Lift Challenge

In Section 2, you will learn more about the science of simple machines, and apply that understanding to doing the more challenging Second Can-Lift Challenge. This time, your device must provide enough an advantage so that you can lift a heavier can twice as far, now 20 centimeter, in the time allowed, which will be 15 seconds.

You will be designing your own device, now that you've learned about different approaches in Section 1, and built and tested some of them. Near the end of this work, you will write up a case study of how your idea developed, and include this in your final presentation. Finally, after your presentation, you will apply what you've learned to a real-world situation, like Cliff's Challenge, where you need to lift something heavy without enough force to do it directly.

Sequence for Doing Section 2

The following are steps for completing Section 2 of Machines That Help:

1. **Reading the Challenge** -- You've just finished this.

2. **Rewriting Product Specifications** -- In Section 1, you wrote ideas concerning your device in the Product Specifications page of your Design Diary. Since the challenge has changed, you will need to revise your specs as well.

3. **Whiteboarding** -- With the revised Product Specifications list in mind, you might want to update your design ideas in a whiteboarding session. Afterwards, create your own summary in the "My Whiteboarding Summary" page of your Design Diary.

4. **Learning About Combining Different Design Plans** -- Since your task has become more of a challenge than before, you will definitely need more help from the device that you design and build. You will learn about two approaches to doing this in the activity entitled, "Combining Plans to Get the Advantage You Need" (pages 50-51).

5. **Design a More Complex Model** -- You will propose ideas for combining some of the basic designs to make plans for your best Can-Lift device to date.

6. **Pin-Up Session** -- You'll present your new designs that may involve combining or improving design ideas in a pin-up session. For this presentation, you'll also be asked to tell which design rules-of-thumb influenced your decisions, and also tell when an idea "just came to you" as you tried to creatively bring different ideas together.

Second Can-Lift Challenge

7. Build Your Device, Show It in a Gallery Walk and Do Whiteboarding -- You'll next build the device you've planned and refine it. A gallery walk will follow where you will get no more than 2 minutes to discuss your device. In a Whiteboarding session, you will record new issues and put ideas of this session in your Design Diary.

8. Learning the Science of Simple Machines -- You will read and learn about ideas like mechanical advantage and work and simple machines (pages 52-53). You'll then be shown two ways to figure out with numbers and calculate the mechanical advantage of devices (pages 52-53), including your own device. A list of key technical terms related to simple machines (pages 62-63) is available for you in the Appendix.

9. Continue with Designing and Constructing a Better Device -- Having done the science you are expected to know when studying simple machines, you'll get more chances to improve your own Can-Lift devices, combine ideas in new ways so that they provide more mechanical advantage, or less if that is what you prefer. You might also do an "Extra Mile" reading (that means it is optional) on what "What is a Model?" (pages 64-65) to find out what they do for scientists and designers the world over.

10. Gallery Walk and Whiteboarding -- You will have a gallery walk where you will get no more than 2 minutes to discuss how you improved your device. In a Whiteboarding session, you will record new issues that have come up during section 2 on the board. You will capture the main ideas of this session by completing a "My Whiteboarding Summary" page for your Design Diary.

11. Final Redesign of Your Improved Can-Lift Device -- After seeing simple machines from both the science and technology points-of-view, you'll brainstorm and propose the last changes to your devices. You'll put your new ideas into practice in your Can-Lift devices and record performance tests of your ideas in your Diaries.

12. Final Report and Presentation -- Using how-it-works drawings, you'll prepare a case study report on the making of your final redesign (see page 56), and then you'll present your final design to your classmates. For your presentation, you will measure your devices' performance and calculate its mechanical advantage.

13. Review and Summary-- You'll do some end-of-section review questions to see how well you understand simple machines and can figure out how much they help.

14. Make Recommendations To Help Someone With a Real Need -- For your last task in *Machines That Help*, you will write a report to one of four groups (see page 60) who need help in lifting heavy things. You will design a device that you propose they use. Your explanations and the ideas proposed are equally important in this task, where you apply what you have learned to a situation similar to what you have just studied.

Why Do Devices Make Tasks Easier?

Advantages and Trade-offs of Simple Machines: The Mathematics

Yet another way to “see” how a simple machine gives you an advantage with trade-offs is by looking at a formula that allows you to make predictions about how those devices perform. To use the formula, you need to know two things: where the Applied Force is, and where the Load is. Here is the formula:

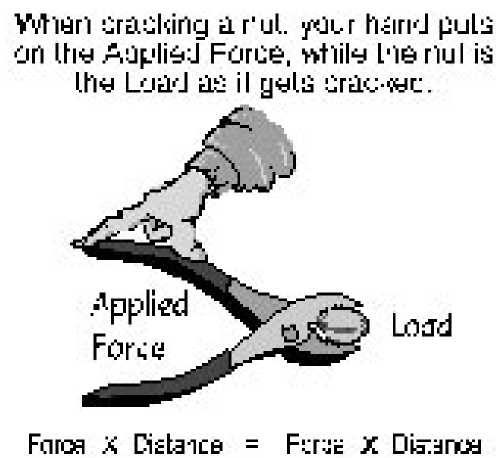
Applied Force Side		Load Side
Force X Distance	=	Force X Distance

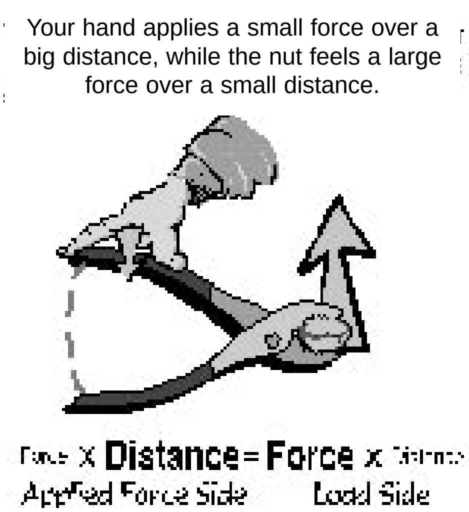
This formula applies to most simple machines and says that the distance the applied force travels TIMES the Applied Force is going to be equal to the force felt by the Load, times the distance that the Load travels. Let’s see what that looks like with two examples.

Applying the Force x Distance Formula: Case 1

Here is an example of a task using simple machines that you may have recently done -- cracking nuts, only this time with a pair of pliers.

Look at the device in use to the right. As with any simple machine, you first need to figure out where the Applied Force and Load are located. With both a nutcracker and a pair of pliers, where the user pushes or pulls the device is the location of the Applied Force. The Load is the area where the device acts on something. With nutcrackers and pliers, this is area where the jaws crush the nut.



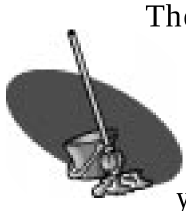


Now let’s look at the pliers as they are being used, and see how the trade-off work with this familiar device. You can see, and know from experience, that the force on the Applied Force Side and the force on Load Side are not equal. Still, something about how far each force moves balances things out -- the smaller forces goes further, while the large force goes a short way. By multiplying the Applied Force times the Distance of each side, and then doing the same on the other, you find that the product for the Applied Side IS EQUAL TO the product for the Load Side. A small force traveling a long way is equal to a large force traveling a short distance.

Why Do Devices Make Tasks Easier? (cont.)

Applying the Force x Distance Formula: Case 2

Here is an example of a task using simple machine that can keep you from wearing out your pants and give you a break from some rough work: cleaning the floor.



The mop is a simple machine that allows you to move a piece of wet cloth at the end of a wooden rod much farther and faster than you move your hands holding the mop handle. In addition, it keeps you from taking a position that is not "friendly" to your body, and that can make your muscles ache after just a short period of time.

So how does a mop help? First, you need to determine where the Load is and the Applied Force. The hand closer to the middle of the mop applies more force, so let's look at that. This would be the Applied Force side of the mop. The mop head that is cleaning the floor would be the Load. (The floor pushes up on the mop as much as it presses down on the floor!)

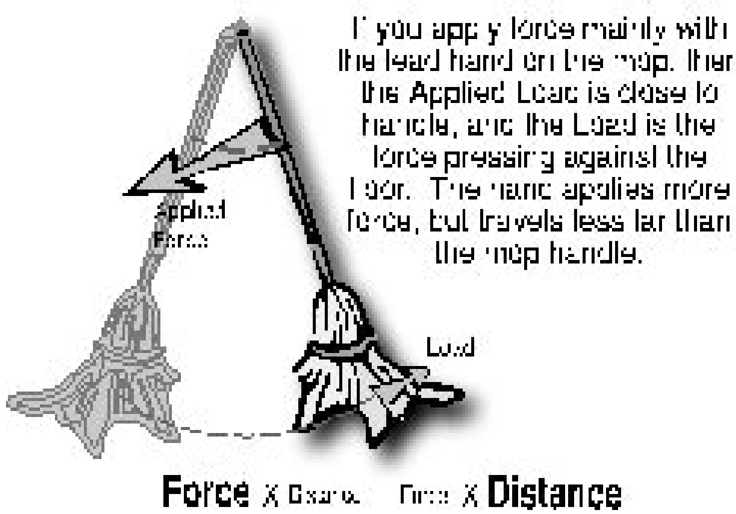
The formula for simple machines talks about both the size of the force, and the distance traveled. During normal use, the hand moves the mop a short distance, less than half a meter, while the mop head could travel three times that amount.

The equation then tells us that the distance the Load travels is three times the distance traveled by the hand. It also says that the Applied Force the hand supplies is 3 times greater than the force put on the floor.

What other devices work in similar ways? Does a broom? What are some others from around the home or shop come to mind?

Homework

Use the Distance-Time formula to illustrate the benefit and trade-off of your current Can-Lift device. Use small and large force arrows with your drawing and small and large letters when writing out the formula. Then pick one other device and make a similar illustration.



Writing a Case Study

How Do Your Write a Case Study, and What Will You Do With It?

To learn more about simple machines, mechanical advantage, and trade-offs, each group will examine products and write a case-study report about it. Case studies are short essays about an individual product that report key ideas designers need to know.

Pick any product that you are familiar with, enjoy using, or would like to learn more about as your subject of study. Use it, watch how others use it, and read about it. When you are done with your investigation, you will write up the case study and contribute it to a Case Library of Machines That Help that you and others can review to get ideas for design improvement.

Traits of a Good Case Study

To do a good case study of a machine that helps, do as many of the following things as seems appropriate:

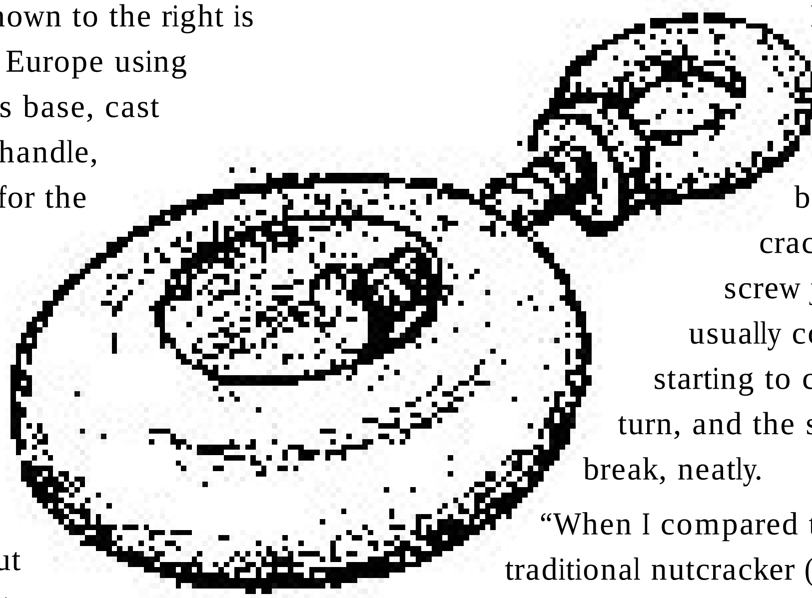
- • write about how the device works;
- • make drawings that show the working mechanisms and forces acting on the product when used;
- • write your own version of product specifications for the product;
- • estimate how many times easier using the device is versus doing the task by hand (if possible);
- • write about your observations of others using the product (optional);
- • use an illustration or photograph of the device, or of the device in use (optional);
- • write any conclusions from product comparisons you've done with similar devices (optional); and,
- • report on interviews with focus groups you conduct (optional).

Your class may want to devise a formatted sheet that is one or two pages in length for entering your final case study report. Making all of your writing fit into one or two page form might seem difficult at first – but it also might help other readers quickly figure out whether what you wrote will help them with their designs.

The sample case study to the right might help you. It focuses on a screw-type nutcracker with a wooden base.

# of Your Can-Lift Device

A Sample Case-Study: The Nutcracker



The nutcracker shown to the right is made in northern Europe using maple wood for its base, cast iron for its round handle, and plated metal for the shaft with screw threads on it. The wooden base is circular with smooth, sanded edges -- this part of the nutcracker is about the size of a donut. A large hole is drilled nearly through the center of the nutcracker's top. A smaller hole with threads that match the shaft's threads is drilled into the side of the wooden base. The nutcracker weighs nearly 3 Newtons -- as much as 3 apples! The metal handle weighs a bit more than the wooden base.

You use this nutcracker by first putting a nut into the wooden bowl. You then turn the cast-iron handle to "tighten the screw". The force applied to the handle moves the shaft along its threads, closer to the nut. You keep turning until the flat face of the threaded shaft pushes the nut against the opposite wall of the wooden base.

To crack the nut, you turn the handle and a bit more force. This makes the shaft apply a much greater force against the nut's shell. The angle of the screw threads makes the job of cracking nuts much easier -- maybe 20 times easier.

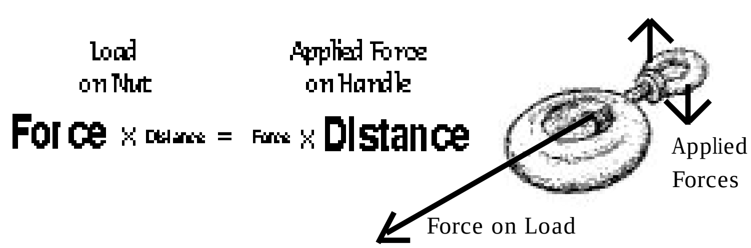
During one product comparison session, a user said, "I like the wooden nutcracker because I control the cracking better. If I turn the screw just a little and slowly, I usually could hear the shell just starting to crack. Another bit of a turn, and the shell would break, neatly.

"When I compared this with the traditional nutcracker (see right), I found that sometimes the nutcracker was hard to control. The shell cracked so fast that I still was squeezing after the shell was broken. The follow-through after the shell broke would crush the nut meat inside.

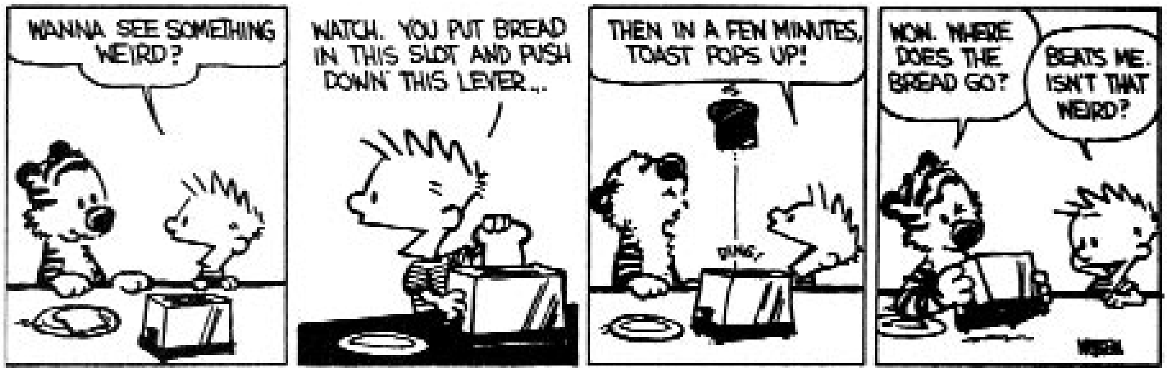
"The European nutcracker seems safer, too, because you can cover the opening with your hand where the nut's shells would otherwise explode out from its wooden base."

The key specifications the designers of this nutcracker may have had in mind were:

- need to use low force to crack nut
- device provides good mechanical advantage for better control
- safe when user covers opening with hand
- comfortable and sized well for the hand

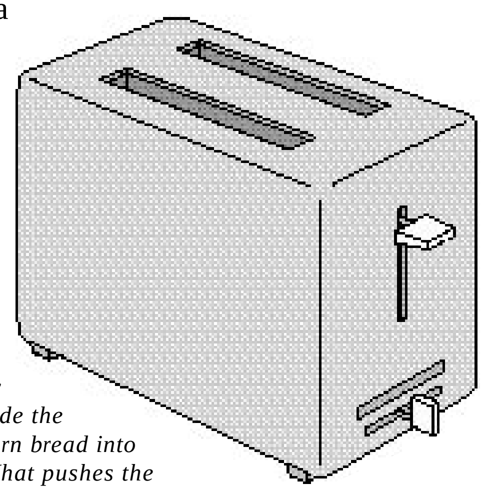


Making Your Own



You often learn the most about a topic when you have to explain it to others. You'll be explaining how your devices work when you are finished your designs. You will be asked to show "how-it-works" drawings so that others can understand your machine.

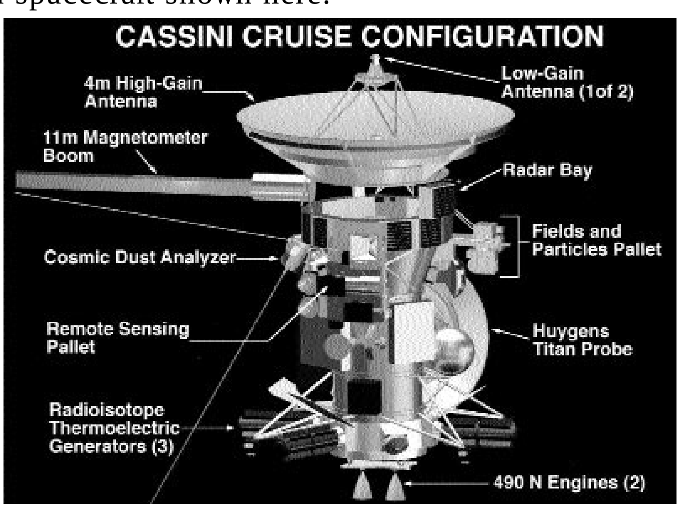
The Calvin & Hobbes cartoon above shows a child's curiosity for a household product and how it works. People, especially small children, have all sorts of ideas about how devices work. Some devices are easier to understand than others. What is Calvin's big confusion about the toast and the toaster? What explanations would help to make things clearer to him and Hobbes?

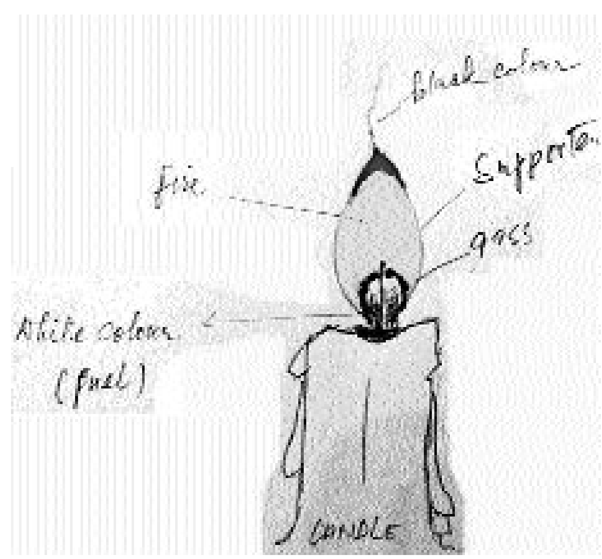


What key parts inside the toaster turn bread into toast? What pushes the toast back up when done?

How-it-works sketches attempt to explain things by telling stories about them. Such drawings help explain complicated things by highlighting some things and eliminate others. This allows us to concentrate on some details and not others.

Labeling — How-it-works drawings help make basic and more complex devices easier to understand. One way to do this is to label the parts of a device, like the candle and spacecraft shown here.





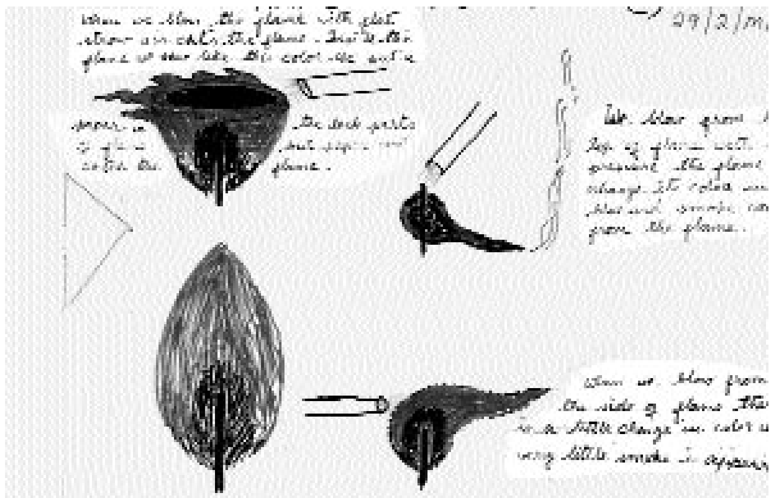
Naming the parts of a candle or spacecraft can help tell the story of how each works.

How-It-Works Drawings

Illustrators of technical magazines and books use many different kinds of drawings to explain complex things. With labels, they can get people to notice things they might otherwise miss. With a series of pictures, they can show how to use a device like a food processor or blender, or tell someone how to take apart or put together a bicycle, or even explain how a horse runs.

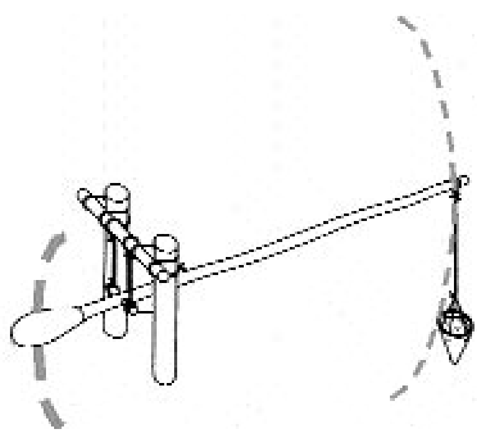
What follows are a series of techniques that illutrators use to explain things and make them clear to a reader. Use those techniques that you think will make your How-It-Works drawings clear to others.

<u>Series of Pictures</u> — An ordered set of drawings can show things that a single drawing cannot. Here are pictures of experiments that a student conducted when investigating the nature of a candle's flame. He tried to see the inside of a flame by blowing through a straw with a narrow opening. This gives a view of a candle's inner parts that simple labeling cannot show.



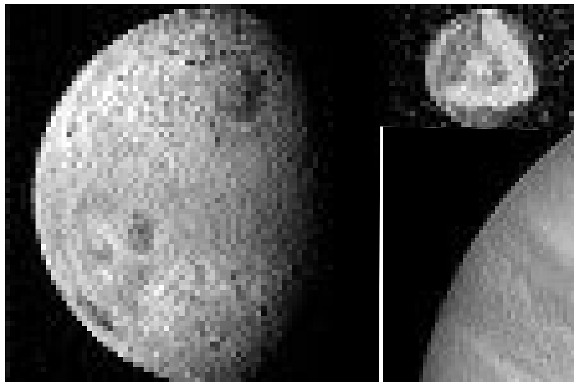
Another way to show how something works is to use a series of sketches and use words to explain your ideas.

<u>Distance-Travelled Lines</u> — With sketches you draw, or pictures you make of a device, you can always add a few lines that tell more about how the object works. Using a dotted line can help show the distance that a device travels when in use. This information can be very helpful when doing calculations and making measurements, to show how much a machine helps.

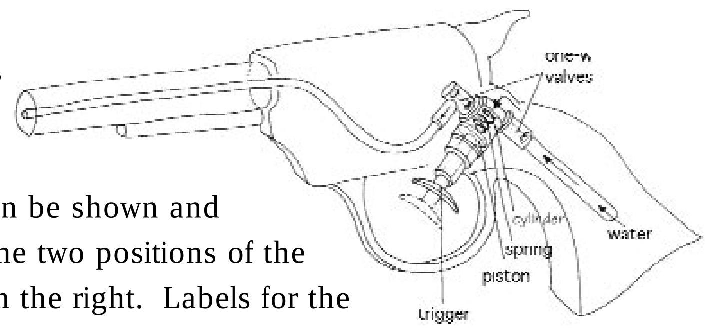


You can get a picture of the advantages and trade-offs that simple mechanisms and machines provide by looking at the diagram to the right. The lines show the distances traveled by the user's <u>applied force</u>, the l<u>oad</u> that the machine is designed to move. The thickness of the line can be used to represent how much force is applied -- the thicker the line, the more the force. The Egyptian shadouf above is a classic 1st-class lever. The heavy counterweight travels a smaller distance than the lighter bucket filled with water being moved for irrigation, but more force is being applied to do this.

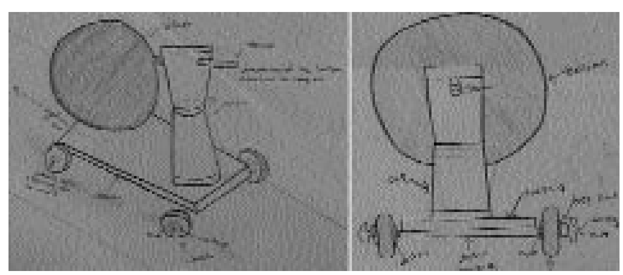
Making Your Own How-It-Works Drawings (cont.)



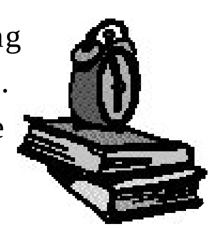
Cut-Away Picture — One way of showing how a thing works is to have a cross-section or cut-away view of an object. With this view, you can see both the outside and inside of the object. The cut-away view of one of the planet Jupiter's moons, named Io (pronounced "eye-oh"), shows the core and an area of molten rock. Io is believed to have more volcanic activity than any other planet or moon in our solar system.



Transparent View — Another technique that illustrators use to explain how something works is to make the outer surface of an object "see-through" or transparent. You then can see the main parts inside the device easily. Movement can be shown and how the mechanisms work or interact -- look at the two positions of the same trigger in the drawing of the water piston on the right. Labels for the pistol's parts also tell more of how the water pistol works. Notice that the tank or reservoir that holds the water supply is not shown -- adding this detail might have made the drawing too complicated.



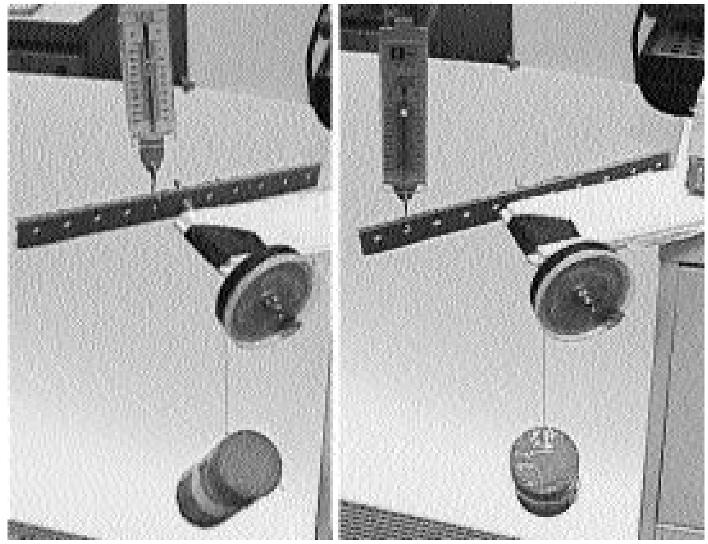
Best Perspective — When making a drawing that explains things to other people, you get to make design decisions, ones that a graphic artist often makes. (Graphic artists design brochures, illustrated books, and even websites.) The team that drew the sketches on the right chose to make two drawings of the device. The head-on perspective (on the right) helps show the spacing between the wheels and chassis. This feature of the design is hard to see with the angled view in the left-hand drawing, or a side view.



Homework 1. Search through magazines for illustrations that show how something works. Find one that you can either cut out, photocopy, or trace, and bring it to class.
2. Make an improved how-it-works drawing for your can-lift device. Pick the best one among those made by your design team. Present it to the class, and tell of its strengths and areas needing improvement.

Cranks & Windlasses (continued)

Experimenting with Different Windlass Designs



One of the experiments you might want to do when developing Design Rules of Thumb for the windlass is to make the shaft that winds up the string larger. You do this by adding a disk to the shaft, and locking it in place on the axle, so that when the crank turns the shaft, the disk turns as well. You can explore this by following the steps for the Second and Third Designs below.

Second Design: Windlass with a Disk

1. Use toy car wheels, lids from jars, yogurt cups, tennis ball containers, even an empty soup can to make a disk for your windlass. *Vary the diameter of the disk by the items you choose as a disk.*

2. Punch, poke or drill a hole that is just slightly larger than the diameter of the axle through the center of the disk.

3. Lock the disk on to the axle using two opposing nuts. Tighten the nuts together with pliers.

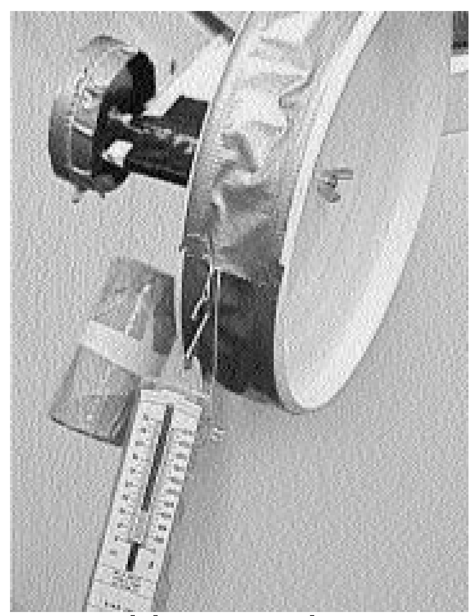
4. Tie or glue a piece of string to the drum so that an object can hang from the string.

Third Design: Building a Windlass with 2 Disks

The third windlass that you might want to build does not use a crank at all -- it has two disks, as shown to the right. With this design, you get to choose which disk holds the cord that raises the can, and which holds the string that you pull to make the windlass work.

You can use any material with the shape of a cylinder for either disk, including lids, throw-away CDs, or even a pair of frisbees. The main item you vary with this design is the <u>diameter</u> of the two disks that make up your windlass.

When you report the results of your experiments to the class, try to tell others which of the above designs may have a special advantage when raising a can over a long distances.

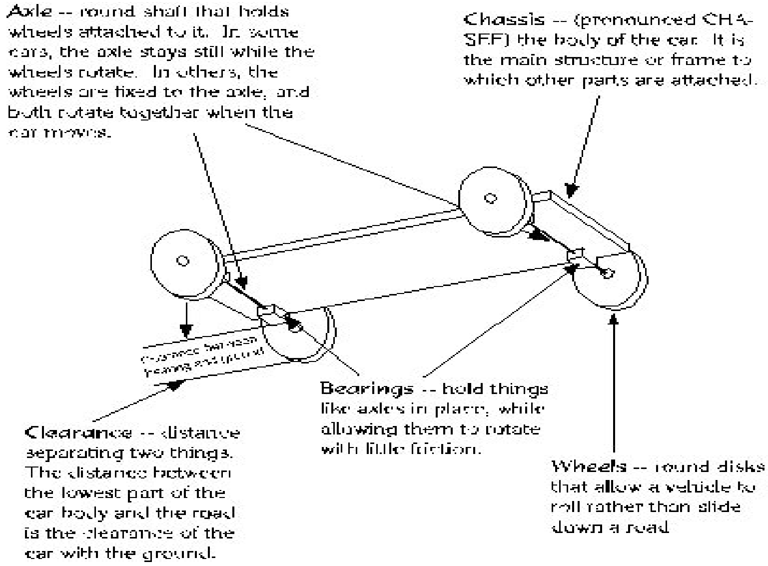


A second drum was made using two frisbees joined back to back with nuts and tape

Can-Lift Extra Helper Plan:

The wheel-and-axle system you will build is called a “coaster car” and is used in the Learning By Design™ unit entitled *Vehicles in Motion*. The car you will build is just a flat body with wheels and axles. When you finish building it, make adjustments so that it travels straight and with as little friction as possible.
If you have already done the *Learning By Design™* unit entitled *Vehicles in Motion*, this should be an easy task to do.

Coaster Car Parts and Terminology



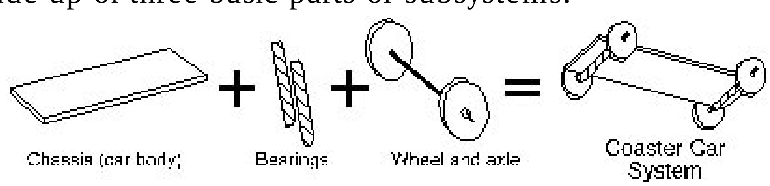
Outline of the Coaster Car Building Instructions

The following instructions for building a coaster car are divided into six parts:

A. Introduction to Building a Coaster Car
B. Materials You Will Need
C. Helpful Information and Explanations
D. Constructing Your Car’s Bearings
E. Connecting the Wheels to the Axle
F. Attaching the Bearings to the Chassis

A. Introduction to Building a Coaster Car

You will be making a coaster car, which is made up of three basic parts or subsystems:
a. a chassis or body;
b. a pair of axles with two wheels each; and,
c. bearings to hold axle or wheels in place
while letting them spin freely.



B. Materials You Will Need

Your teacher will give you the following materials to build your coaster car.

Materials List

1	piece of 10x30 cm foamcore or cardboard	2-4	1/4” thread wing nuts
		8	1/4” washers
2	6” carriage bolts, coarse thread	1	roll masking or other tape
4-6	1/4” thread regular nuts	1	Straw for use as bearings

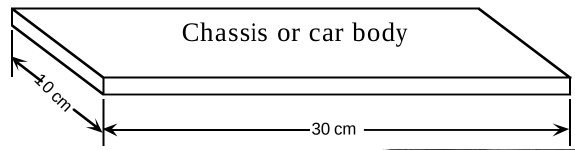
Using Wheels & Axles

C. Helpful Information and Explanations

The following are some facts that might help in using the tools and materials you need to make a coaster car.

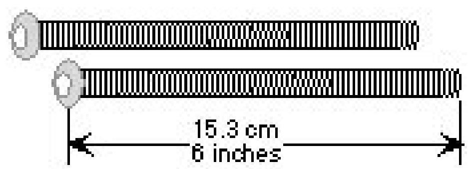
- The car's chassis or body can be made of any rigid, light material, like foamcore or cardboard.
- Carriage bolts are threaded shafts with a cap at one end that serve well as car axles.
- A **regular nut** is a six-sided piece of metal, with threads through its center, used to hold or fasten things in place. A **wingnut** is a similar kind of nut that can be tightened with the fingers.
- A **washer** is coin-shaped with a hole in its center, and is used to make space between things.

Help in Using Adjustable and Needle-nosed Pliers

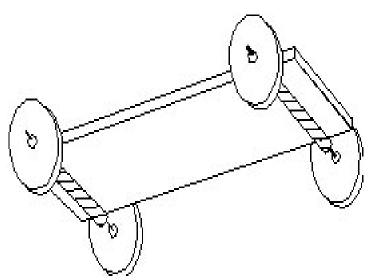


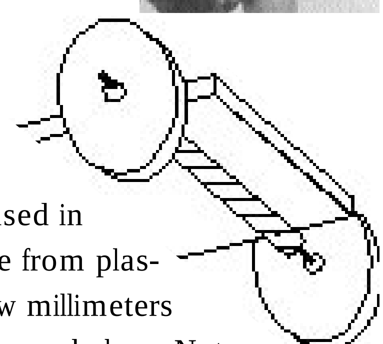
- Pliers are like a pair of strong hands that give you a firm grip on something without hurting yourself when you squeeze hard. Adjustable pliers have short jaws and can be set to grab narrow or wide objects.

  Needle-nosed pliers have longer jaws that help you reach hard-to-get objects.

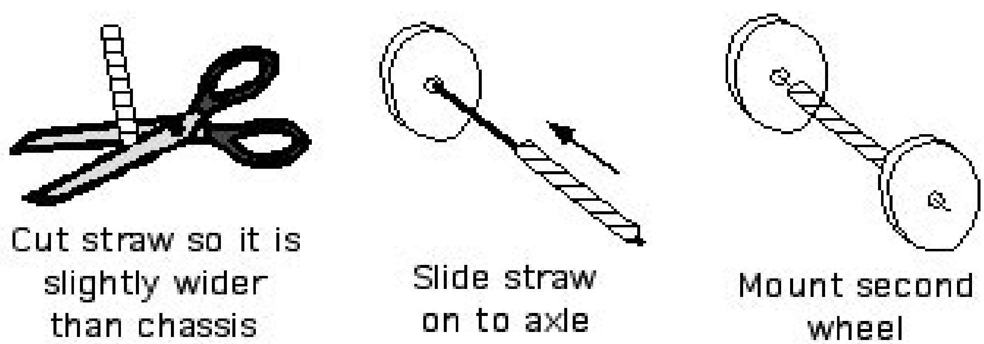


D. Constructing Your Car's Bearings





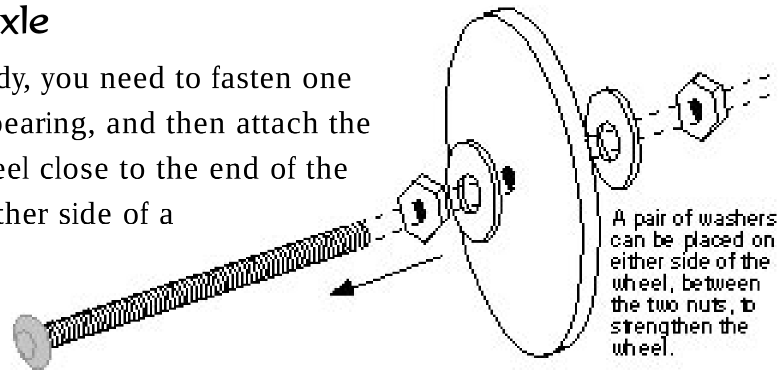
A **bearing** holds something in place while allowing it to move freely in certain ways (like rotating). There are many kinds of bearings used in model cars -- you will be using **bearings** made from plastic straws. Measure the straw so that it is a few millimeters wider than the car body. Cut each straw as shown below. Note the order that the wheels and straw will be attached below.



Extra Helper Plan: Wheels & Axles (continued)

E. Connecting the Wheels to the Axle

Before attaching the bearings to the car's body, you need to fasten one wheel to the axle, slide the axle through the bearing, and then attach the second wheel to the axle. Fasten the first wheel close to the end of the axle with the cap on it. Place two nuts on either side of a wheel and then use pliers to tighten the nuts firmly against the wheel, locking the wheel in place on the axle. Here are the steps:



Directions for fixing a wheel near the end of the axle with the cap on it:

E1. Thread a nut along the length of the carriage bolt, so that it rests next to the bolt's cap.

E2. Slide a wheel into place on the axle so that it rests snugly against this nut.

E3. Spin a second nut so that it presses against the other side of the wheel.

E4. Grab the regular nut with a pair of adjustable pliers and turn the wingnut with your hand. E5.

E5. Tighten the nuts in opposite directions to lock the wheel in place between them.

E6. Check that the wheel is firmly held so that the axle and wheel turn together.

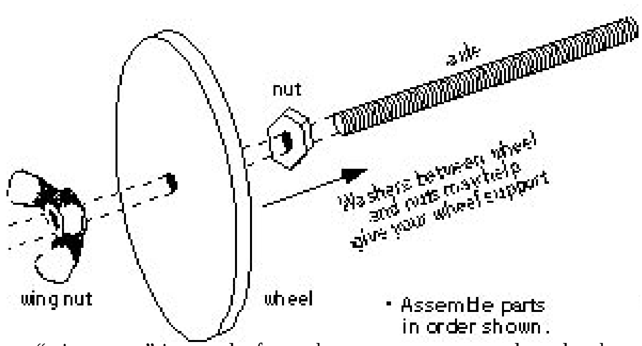
E7. Slide the bearing along the length of the axle.

Directions for placing and fixing the second wheel near the end of the axle without the cap:

E8. Put one flat or regular nut on the threaded axle by turning it in place.

E9. Slide the wheel after it until it is pressed against the first nut.

E10. Spin on a wingnut or regular nut. Tighten with pliers in the usual way.

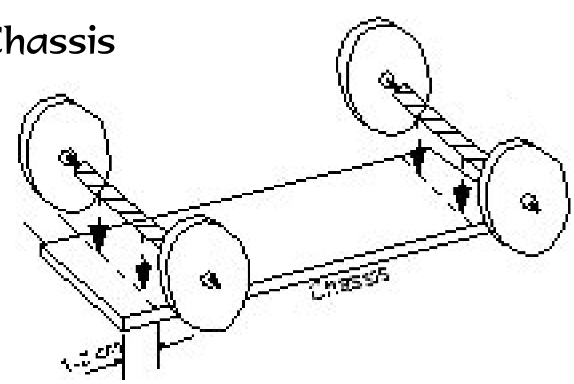


Note: You may use "wing nuts" instead of regular ones to secure the wheel firmly to the axle. Washers may be placed between the wheel and nut.

Tighten nuts against the wheel with your hand and a pair of pliers. Axle should turn when wheel is rotated.

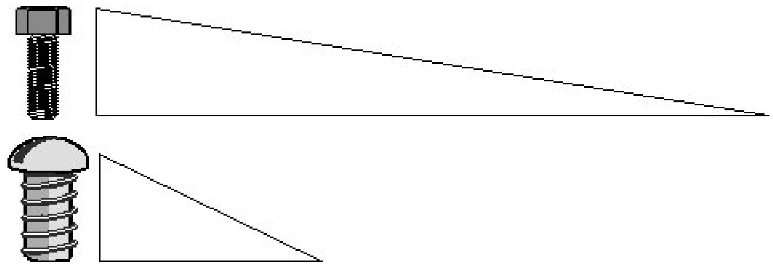
F. Attaching the Bearings and Wheels to the Chassis

Be careful to line up the bearings so that the two axles are parallel to one another. If the front and rear axles are aligned improperly, the wheels will point in different directions and your car's performance will suffer.



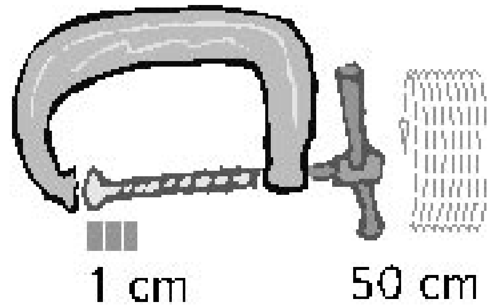
FACTSHEET: Mechanisms with Screws

Ramp in a Screw

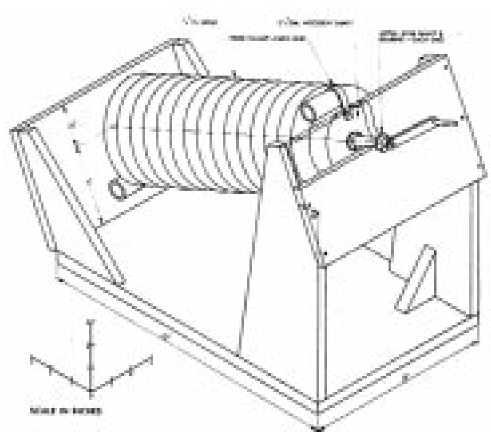


The screw is one of the five types of simple machines and is made as if an inclined plane or ramp has been wrapped around a shaft. If you place a ramp-shaped of paper next to a pencil, and then wrap the paper around the pencil, you will make something that looks like the threads of a screw. Putting the paper at a steeper angle would yield coarse screw threads, while a gentler angle would make fine-threaded screw.

Just as it takes fewer steps to walk up a steep ramp, it take fewer turns to tighten a screw with coarse threads, but it takes more force. What is the advantage and trade-off with fine threads? It is easier to turn such a screw, but you have to turn more times to complete the task.



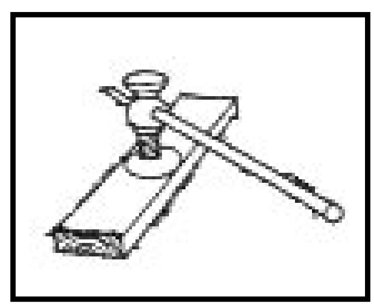
By measuring the distances traveled by the applied force and load, you can figure out how much a C-clamp helps.



Archimedes Snail

A Greek man named Archimedes made a number of discoveries involving water -- the most famous was an explanation for why things float or sink. One invention he is credited with devising is a screw-like device that raises water. Archimedes' Snail is turned with a crank at its raised end, and it has screw threads or a tube wrapped around a shaft. The low end is under water. As the snail is turned, water is raised along the threads of the "snail" until it comes out the top end.

Screw in a Car Jack



One of the heavy things people need to lift in modern times is a car! When your car has a flat tire, you replace the bad tire with a spare by lifting the car off of the "bad" wheel, taking the wheel off, replacing it with the spare from the trunk, and then lowering the car. One way to lift a car is with a screw jack -- the long lever bar turns the screw, which raises up the flat platform at the top of the jack that holds up the car.

Homework: Collecting Cases of Mechanisms with Screws

Find at least two cases of devices or structures that use screws as part of the mechanism of the device. Pick products where the screws are not used as fasteners, say to hold things together. Instead, the screw should act as part of a working mechanism in the product.

Trade-offs & Simple Machines:

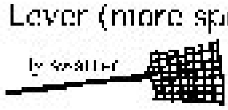
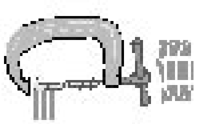
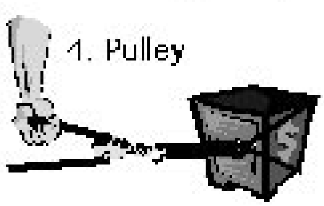
Trade-Offs and Simple Mechanisms

Machines can help people do things they cannot do by hand or on their own. They lift things heavier than people can lift -- think of a jack raising up a car or a crank that helps pull a boat from the water. Machines can get to places people cannot reach -- store owners have long poles with a gripping jaws at the end for grabbing things that are out of reach. And some machines can help people do things faster than they normally can do -- the speed of the end of a flyswatter or tennis racket travels much faster than the hand that uses it.

For every advantage a machine provides, there is always a trade-off. To lift a 1000-kg car up from the ground with a jack, your arm must repeatedly apply a force on the jack, which totals a distance of many meters, in order to raise a car a few centimeters.

What You Get and What You Have to Give

The table that follows tells a story about different types of devices that give an advantage to users, and the trade-off that goes along with using them. Only one or two examples are given for each type. Can you think of others, and tell what the advantage and trade-off is for each?

Type of Device	Advantage	Trade-Off
1. Inclined Plane, Ramp 	You use less force going up a longer ramp...	...but you need to travel a greater distance.
2a. Lever (more force) 	Can opener transmits more force in cutting the can lid than your hand applies...	...but your hand travels much farther.
2b. Lever (more speed) 	Fly swatter head moves faster than your hand...	...but with less force than your hand applies.
3. Screw 	C-clamp applies large gripping force with only a small force on handle...	...but your hand must go around much further than the screw head moves.
4. Pulley 	User pulls with less force than the hook does to the safe...	...but your hand travels further than the safe does.

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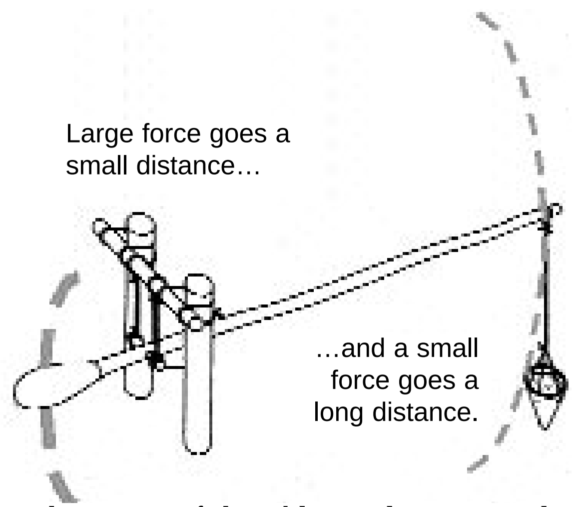
Why Do Devices Make Tasks Easier?

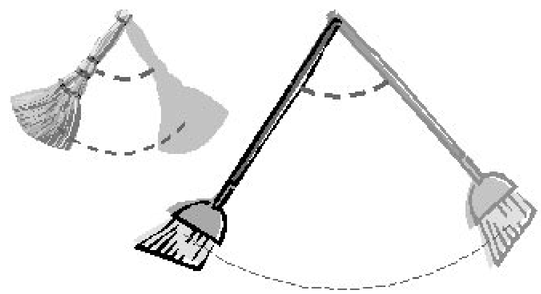
Pictures of Advantages and Trade-offs



One way to picture the advantages and trade-offs that simple devices provide is shown in the diagram to the left. This device raises water in a cone-like container held by a rope on the long end of a pole. A large force on the short end of the pole, near the pivot, comes from a counter-weight and from the user.

The *length* of the lines show the distances traveled by the user's Applied Force and the Load that the device moves. The *thickness* of the line represents how much force is applied -- a thick line means that more force is being exerted, and a thin line means less force.

In the cases of the older and more modern brooms, the Applied Force near the top of these 3rd-class levers has a short, thick line, while the brush areas have longer, thinner lines. Dust and dirt don't need much force to move. The hand applies a large force over a short distance, while the broom head travels much farther. What advantage does the broom with the long handle have over the one without a handle? How do the dotted lines tell this same story?



What Is a Simple Machine?

The devices described in the table on page 33 have something in common -- they give users advantages in doing tasks, but combined with trade-offs. In science, these "machines that help" are given a special name: simple machines. In total, there are five different classes of simple machines:

(1) three kinds of levers; (2) inclined planes; (3) screws; (4) pulleys; and (5) wheels-and-axles.

You may notice that you have been given plans to build four of the five types of simple machines in your first attempt at making the Can-Lift device.

Remembering the names of all five types of simple machines is not all that important in this unit, or in Learning By Design™ in general. However, being able to explain how each simple machine works -- how they provide an advantage, with an accompanying trade-off -- is important. Learning to combine these simple machines to get even more advantage will be critical for the rest of this unit.

Devices that combine one or more simple machines are called complex machines. If you found that your first Can-Lift device benefitted from using the added helper plan for a coaster car, then using even more ideas of simple machines together in the same device may help lift even bigger cans.

Moral of the Story Trade-offs are the name of the game with simple machines. You don't get an advantage without some sort of trade-off. In other words, there is no "free lunch" (something for nothing) when it comes to using simple machines.

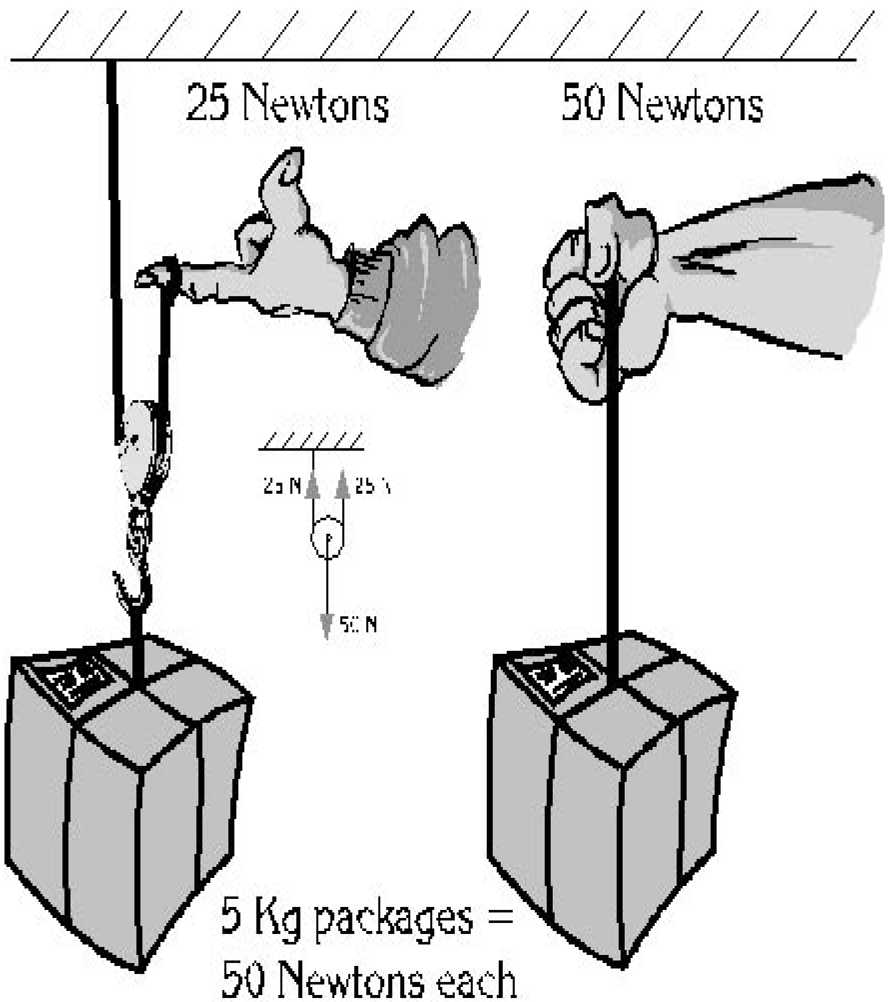
Can-Lift Plan 3: Using Pulleys

Pulleys from the Past

The ancient Greeks, especially those from Athens, held more powerful foes at bay because of their fleet of ships that made up a powerful navy. To move their ships to the land for repairs, they used pulleys as long as 2300 years ago.

The simplest pulley is wheel and axle, with sometimes a hook attached to it. A cord, rope or cable goes around the rim of the pulley's wheel. If you take two or more pulleys and connect them with the same rope, you can make a block-and-tackle, which can lift heavier loads like sails or a boat.

Look at the case of a simple pulley in action to the right. Two people are holding up a 5 kilogram box. The strong-armed person is lifting directly with a rope, which takes a force of about 50 Newtons. Using the pulley with the box hanging from its hook, the force needed for a similar box is cut in half. How does the pulley give an advantage?



Try to visualize how the simple pulley works when the person's finger pulls up on the rope. As the person pulls up, the wheel will turn. As the wheel rotates, the pulley will climb half that distance up the left side of the rope and half up the right. Thus for every centimeter than the hand goes up, the pulley and its box will go up half a centimeter. This pulley's advantage is that it can reduce the force to do the task. The trade-off is that your hand has to travel twice the distance in doing the same work.

Using more than one pulley with the same rope can increase the advantage the rig provides. The instructions on page 25 show how to make a block-and-tackle pulley. These more complicated riggings, which used to be found on ships and farms, do help more, but because of <u>friction</u> around the wheels and axles, the advantage each new pulley provides brings less and less advantage.

& Block-and-Tackle

Investigating Your Pulley & Block-and-Tackle

1. Collecting Cases

Some devices use pulleys to lift heavy things -- far fewer use the block-and-tackle. Look around for examples of for pictures of devices that use either. If you can, bring in an example of a device to show others, if this can be done safely and the item is small and not expensive. Make a drawing to show your classmates how each works. Tell how each works by showing with arrows the forces you think are at work in the devices. Be sure to include friction as a force at work when these devices are in use. Look especially in places where heavy things are lifted, like a car body shop, factory, or warehouse.

2. Messing About with the Pulley or Block-and-Tackle

Follow the instructions on pages 24 to build the pulley. Become familiar with the device by using it as designed, and then attempt to lift the can with it. You may want to use a heavier cord for your initial tests. Then build the moveable pulley using instructions on page 25 to make a block and tackle. Improve the design as you think best. Be ready to report what you did to make your device work, decisions you made, and how well it worked.

3. Measuring Your Pulley and Block-and-Tacklet at Work

Use the single-cotton strand of string to find out whether your new device works well enough to meet the challenge. If your string breaks, then tie more strings to your device, one at a time, until it does work. Make repeated observations. Be prepared to report your results, along with drawings of the device. (Look ahead and read about making "how-it-works" drawings -- pages 40-42.)

4. Design and Run Experiments to Find Out What Affects Pulley Performance

Design and run experiments where you test a single design feature at a time in your device that you think might change how much it helps you in lifting the can. The key features to vary (while keeping the rest of the design the same) are: number of times string is wrapped around the spools of the block-and-tackle, type of bearing for the spool, and the diameter of the spools used.

Take repeated readings of your redesigned device by using one or more strings, or use a force meter. Note trends in results and report them in your "My Experiment" Design Diary page. Extract Design Rules-of-Thumb from your tests that will allow others to know how and when to use your device. Don't forget -- test one feature at a time! You might have to do multiple experiments, each with its own Design Diary page.

5. Can a "Wheels and Axles" Helper Help?

If you have time, look over the "Extra Helper Plan: Using Wheels and Axles" on pages 30-32. You might want to consider whether using a cart with your pulley or block-and-tackle would be of advantage. If you think it will, then budget some time to build one and test your idea.

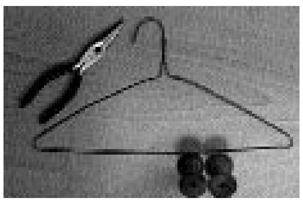
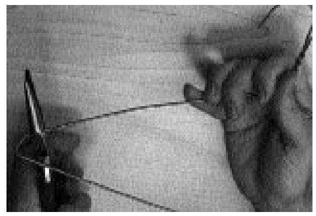
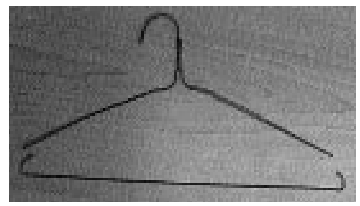
Can-Lift Plan 3: Using Pulleys

Making a Simple Pulley

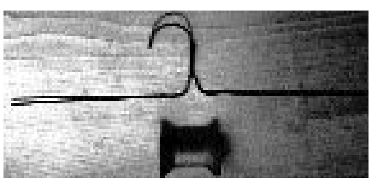
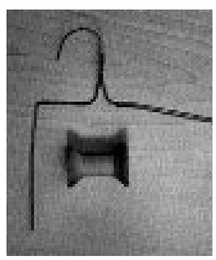
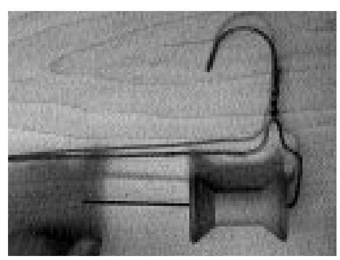
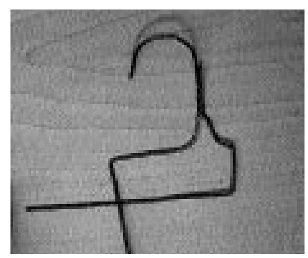
Materials: To make your first pulley, you will need a wire coat hanger and an empty spool of thread.
Tools: You will need some pliers with jaws that can cut wire. Either needle-nose or lineman pliers will do -- be ready for some heavy cutting, given the thickness of the coat hanger wire.

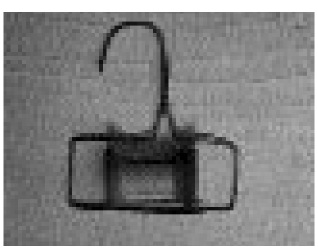
Your first pulley allows you to change the direction that a rope or string is pulled. It may be useful in your design of the Can-Lift challenge if you are using much string in your construction.

1. Collect your materials, and the using your pliers, cut the base of the coat hanger, as shown.

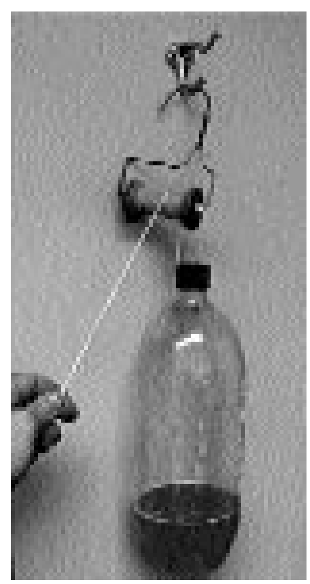




2. Straighten out the two arms of the coat hanger than remain. Place the empty thread spool so that it lies in the center below the hanger's hook. Make sure it is clear of the wire.
3. Place the empty thread spool so that it lies in the center below the hanger's hook. Make sure that the spool will be clear of the wire when it spins.
4. Bend one of the wire arms to make a corner so that it can act as the axle around which the spool will rotate.



5. Bend the second wire arm into a make a corner so that it can act as part of the axle from the other side. Bend this second wire arm a second time so that the two wires form an axle for the spool to spin around. Trim both arms so that each is about as long as the spool is wide.

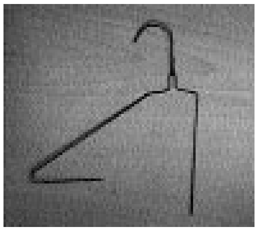


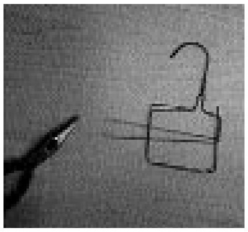
6. Check that the spool will have enough room to spin freely.

7. Place a straw as bearing for the axle. Then slide the empty thread spool over the wheel that is the pulley's axle.

8. Place a string over the pulley to raise an object, like the 2-liter soft drink container shown to the right.

& Block-and-Tackle (continued)



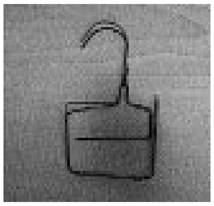


Making a Block-and-Tackle or Moving Pulley

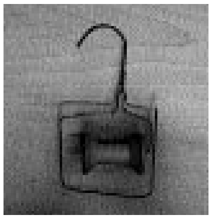
Ships in earlier centuries used block-and-tackle rigs to move heavy things. You can experiment with this simple version after you follow these instructions for building one.

1. Using your pliers, cut another coat hanger as shown. You should make one arm slightly longer in length than you did with the pulley that you made earlier.

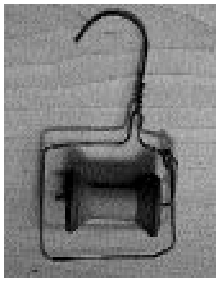
2. Bend the two arms as shown.



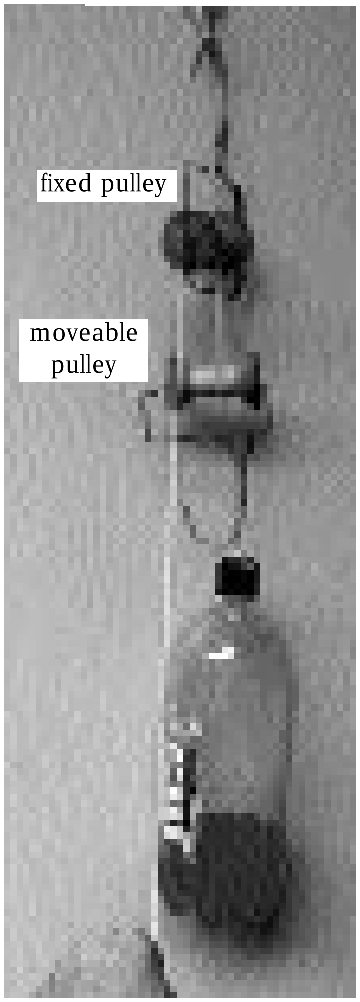
3. Trim the wire arm that will act as an axle. Make sure that there is enough clearance for the spool to spin freely. Bend the other arm up so that it can later be attached to the body of the block.



4. Place the spool and a straw bearing onto the block-and-tackle.



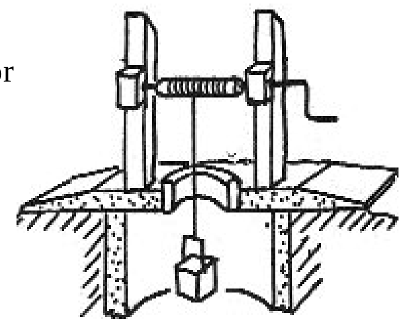
5. Bend the second wire arm so that it hooks over and grabs the body of the block-and-tackle, as shown. This arm will have the string tied onto it and will not move.



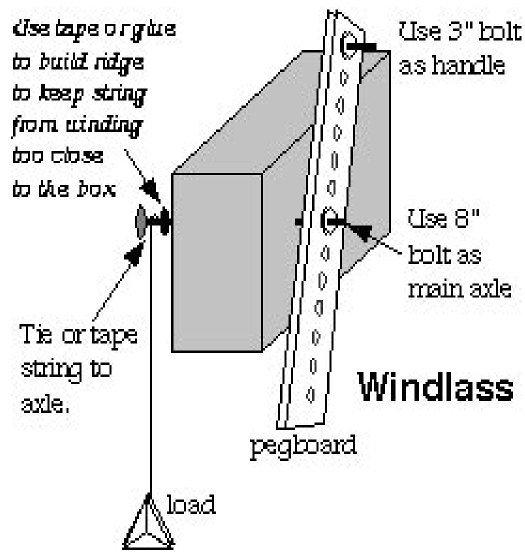
6. Set up the block-and-tackle system as shown, using the simple pulley you made earlier on the bottom and the one you just made on top. Tie the object being moved (soda bottle) to the hook of the moveable pulley.
7. Take one end of your string and tie it to the fixed pulley's bottom arm.
8. Wrap the string around the lower pulley's spool and thread it upwards so that the string forms the shape of a "U".
9. Wrap the string around the spool of the fixed pulley. Pull on this string as shown to raise the weight.

Can-Lift Plan 4: Using

An Introduction to the Crank and Windlass



The windlass has been used since ancient times to raise water from a hole or well. Such a windlass is made up of rope, a crank, and a shaft or drum around which the rope gets wound. You make one by first tying a bucket or other load to one end of a rope, and attach the other end to the shaft of the windlass. Bearings hold this shaft or axle and allow it to rotate freely. The user applies a force to the windlass' crank handle, which applies a force on the windlass' shaft and the rope holding the load. Turning the crank handle winds or unwinds the rope from the shaft, raising or lowering the load from or to the bottom of the well.



Making Your Own Crank and Windlass

Here are the main parts of a model windlass that you will build:
a. a crank arm (pegboard) with handle (3-inch bolt);
b. an axle that turns, with the crank arm on one end and cord on the other end;
c. a body (cardboard box) that supports the axle while letting it spin freely.

Materials

1 - 10 x 40 cm piece of pegboard
1 - small cardboard box
4 - regular hex nuts and washers, 1/4" with coarse thread
1 - 8"-long carriage bolt, 1/4" in diameter with coarse thread
1 - 3"-long carriage bolt, 1/4" in diameter with coarse thread
2 - 3" piece of plastic straw
1 – meter of cord or kite string
1 – piece duct tape

Tools

Wrench or pliers to tighten and loosen the nuts that hold the handle and axle to pegboard crank

Overview of Windlass' Design

The model windlass has three major parts: (a) the load and string; (b) a cardboard body; and (c) a crank-axle system that is held by the body. Unlike a traditional windlass, the model has a crank and handle on one end of the long axle (8-inch chassis bolt), and on the other end is attached a string for raising and lowering the load.
The arm of the crank is made of a long strip of pegboard. Pegboard is an easy material to work with and has rows of pre-drilled holes that are 1 inch apart. In the middle of the pegboard you will be attaching an 8"-long carriage bolt with two nuts. Near the end of the pegboard you will attach a 3"-inch carriage bolt. This will act as a handle for the windlass you are building.

Cranks & Windlasses

Investigating Your Cranks & Windlasses

1. Collecting Cases Invoving Cranks & Windlasses

Mechanical devices often have cranks; a few have parts that act as a windlass. Look for three cases of devices around the house that use cranks or windlasses. Bring in an example of a device to show others, if this can be done safely and the item is small and not expensive. Make a drawing to show your classmates how each works. Use arrows to label the forces you think are at work in the devices. Be sure to include friction as one of the forces at work when the device is used.

2. Messing About with Your Windlass

Follow the instructions on page 28 to build your first windlass. Become familiar with the devices by using it as designed to lift the can. You may want to use a heavier cord for these initial tests. All that is necessary is that you get something working, and improve it in ways that you think best. Be ready to report what you did to make your device work, decisions you made, and how well it worked.

3. Measuring Your Windlass at Work

Using the single-cotton strand of string to find out whether your windlass works well enough to meet the challenge. If your string breaks, then tie more strings to your device until it does work. Repeat these observations. Be prepared to report your results, along with drawings of the device. (You might read ahead to take a look at the layout of a "How-It-Works" drawing -- see pages 40-42.)

4. Finding Out What Features Affect Performance and Testing Them

Design and run experiments where you test a single design feature at a time in your device that you think might change how much it helps you in lifting the can. With this device, the key features to vary are: to wind the cord holding the can around the small diametered axle, or around a larger diametered disk (see page 29, middle); to use a short or long crank handle, or to use a second disk instead of a handle (page 29, bottom). Finally, you can experiment with different types of bearings to hold the axle.

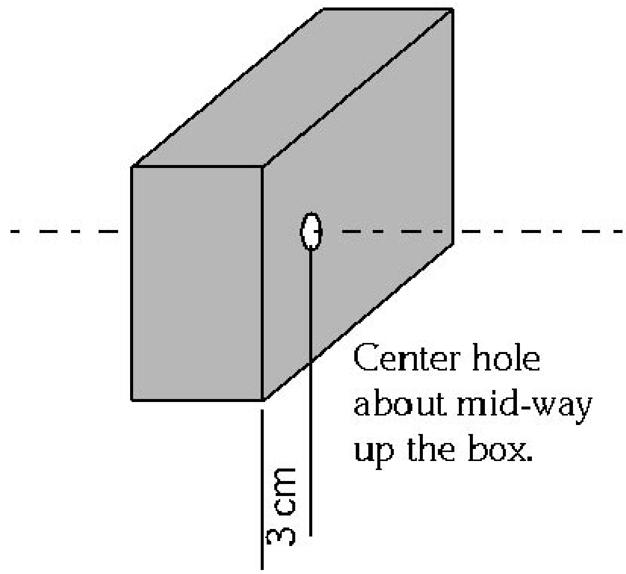
Take repeated readings of your redesigned device by using one or more strings, or use a force meter. Note trends in results and report them in your "My Experiment" Design Diary page. For instance, shortening the length of a handle might make the device harder to use. Extract Design Rules-of-Thumb from your tests that will allow others to know how to use your device. Don't forget -- test one feature at a time! You might have to do multiple experiments, each with its own Design Diary page.

5. Can a "Wheels and Axles" Helper Help?

If you have time, look over the "Extra Helper Plan: Using Wheels and Axles" on pages 30-32. You might want to consider whether using a cart with your windlass would be of advantage. If you think it will, then budget some time to build one and test your idea.

Can-Lift Plan 4: Using

Steps for Building a Windlass

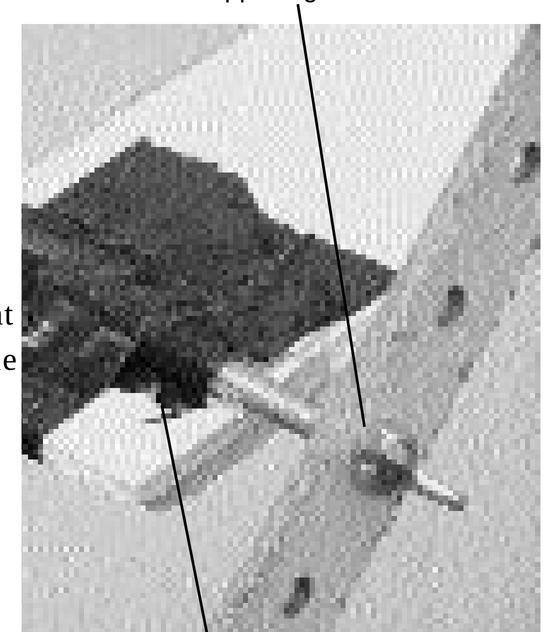


1. Collect the materials for building the model windlass.

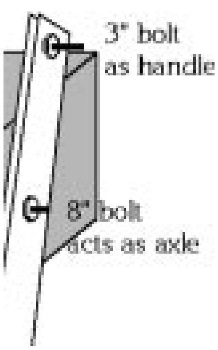
2. Use a pencil to punch a hole through opposite walls of the box, about 3 cm near the box's end. (Leave enough room for the handle to rotate freely.)

3. Put the axle (8" bolt) through both side walls of the box. This long bolt acts as the axle for the windlass. It is what the string wraps around as the axle is rotated. To allow the axle to spin more freely, you may want to insert a straw into the hole as well. The axle should then fit loosely inside the straw bearing.

4. Connect the crank arm made of pegboard to the axle by pushing the threaded end of the axle through a hole in the middle of the pegboard.



5. Lock the crank arm in place on the axle by tightening two nuts on either side of a board together with pliers or a wrench (see figure to right).



6. To connect the crank handle to the crank arm, put a nut on the threaded 3-inch bolt that acts as the windlass' handle, and then push the bolt through a hole near the end of the pegboard crank arm. Put a second nut on the other side of a board, and then tighten the nuts together with pliers or a wrench to lock the handle in place on the crank arm.

7. Tie the cord to the smooth end of the axle with a knot and secure it with tape so that the cord does not slip when it raises or lowers the can.

8. Make sure that the system is balanced, that the axle turns freely, and that the pegboard is locked firmly onto the axle and the string does not slip.

Using Levers

Investigating Your 1st, 2nd and 3rd-Class Levers

1. Collecting Cases Devices With Levers In Them

Pictures to the right are some that are often used in the garden or around the house. Make drawings of at least three devices and show where forces are applied in each of them when used. Bring in an example of a device to show others, if this can be done safely and the item is small and not expensive. Tell others in your own words how you know which type of lever each is.

2. Messing About with Levers

Do the investigation of beam balances, found on pages 16-17. Tell what you learned from your explorations to the rest of your class. Once done, build your own lever (page 17, bottom), and test its use in raising the can. Experiment with the beam's design and the way you place the Load on it. At this stage, you can use a heavier cord and not the fine string to raise the lever you make. All that is necessary is that you get something working, and improve it in ways that you think best. Be ready to report what you did to make your device work, decisions you made, and how well it worked.

3. Measuring Your Lever at Work

Use the single-cotton strand of string to find out whether your design works well enough to meet the challenge. If your string breaks, then tie more strings to your device, one at a time, until it does work. Make repeated observations. Be prepared to report your results, along with drawings of the device. (You might look ahead and read about making "How-it-works" Drawings -- pages 40-42.)

4. Design and Run Experiments to Find Out What Affects Lever Performance

Design and run experiments where you test a single design feature at a time in your lever that you think might change how much it helps you in lifting the can. With a lever, the key features to vary (while keeping the rest of the design the same) are: location of where you tie the string (Applied Force), location of the can (Load), and location of the pivot point. Also, you may want to change the design of the lever bar itself, how you attach the can to the bar, decide whether the can should go above or below the bar, or make a new kind of low-friction pivot.

Take repeated readings of your redesigned device by using one or more strings, or use a force meter. Note trends in these changes and report them in your "My Experiment" Design Diary page. Extract Design Rules-of-Thumb from your tests that will allow others to know when and how to use a lever. Don't forget -- test one feature at a time! You might have to do multiple experiments, each with its own Design Diary page.

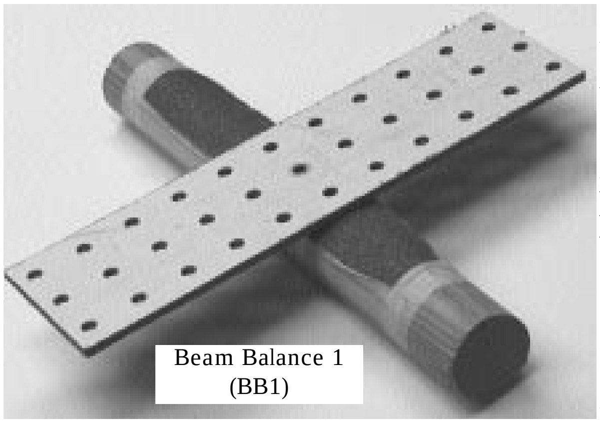
5. Can a "Wheels and Axles" Helper Help?

If you have time, look over the "Extra Helper Plan: Using Wheels and Axles" on pages 30-32. You might want to consider whether using a cart with your lever would be of advantage. If you think it will, then budget some time to build one and test your idea.

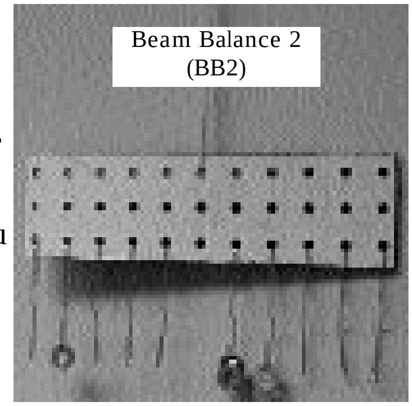
Can-Lift Plan 1:

Two Ways to Build a Beam Balance

* Ideas for this activity are drawn from Tim Barclay's book, Balancing, published by EDC of Newton, MA 02160.



Beam Balance 1 (BB1)



Beam Balance 2 (BB2)

The following instructions for building a beam balance that you can investigate are optional. You can find other instructions for building levers on the next page. You might draw ideas from here and apply them to your own design of those levers.

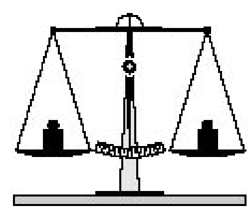
BB1 and BB2 (above) use a 3 x 35-cm long piece of pegboard as the beam. Pegboard's evenly spaced holes are often used for hanging things. These two designs use different types of pivots.

BB1 lays its pegboard flat on a piece of sandpaper that has been glued to the top of the rounded edge of wooden molding. You can do experiments by stacking washers or coins on both sides of the pivot over the pegboard's holes, at the same or different distances from the pivot.

BB2 uses string through a hole in the top row of the pegboard as a pivot. Hanging from the bottom row of pegboard holes are paper clips that have been bent in the shape of an "S". You can place one or more washers or other weights from the paper clips that hang from the pegboard's holes.

First Investigation Topic: The Beam Balance

A good place to start learning about lifting heavy things is to investigate a beam balance and how it works. A beam balance is often used to measure the mass of objects. But how does one work?

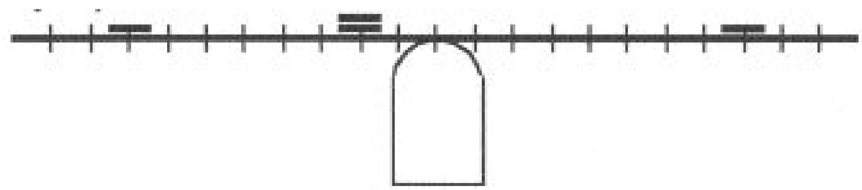


The beam balance to the right has a pan on its left and right side and a pivot in the middle. You put the object you want to weight on one side, let's say the left side, which forces the beam to go down to the left. Then you put a second object whose mass you know on the right-hand side of the beam. If the two masses are an equal distance from the pivot, the balance will be level only when the two masses are equals. -- But what if the pans aren't equal distances from the pivot? Or the pivot isn't in the center of beam? This will be one of your investigations of beam balances.

Messing About with Beam Balances

Your aim in "messing about" with the beam balance is to explore the way its works, and for you to look for patterns in how a beam with washers or some other objects on it behaves. Eventually, you should be able to look at a diagram of a beam like the one on the next page (top) and make two predictions: (a) Tell if the system is in balance or not. (b) If it is not balanced, suggest ways to make it balanced, by moving the weight around, or adding a weight, or moving the pivot. The next illustration shows a beam balance with metal washers on it.

Using Levers (continued)



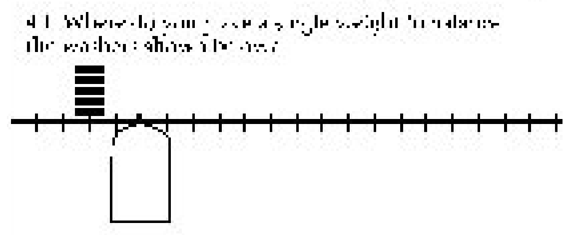
Is this system " balanced"? If not, how could you move one washer so that it would be balanced?

Since you are only going to spend a short while on the beam balance activity, limit your investigations to about 8 washers. Start with just 3 washers and position two so that they rest on the same spot on the beam, and then try to balance the system with the remaining washer. Try to make a rule based on the patterns you notice of balanced systems with different set-ups. Make sketches like the one above of the weights and the system when it is balanced and not. Other tasks include:

• First place the coins on each side on the same spot. Then experiment with having more than one pile on the same side of the pivot, as in the drawing above.

• Experiment with set-ups others may find hard to predict because they seem lopsided to the eye. Look for <u>different ways</u> to get the beam to horizontal again. Be ready to share what you are learning about beam balances in a gallery walk.

Try to answer the problem to the right. Use your beam balance to check your predictions.



<u>Directions on Building a Long LEVER to Lift a Can:</u>

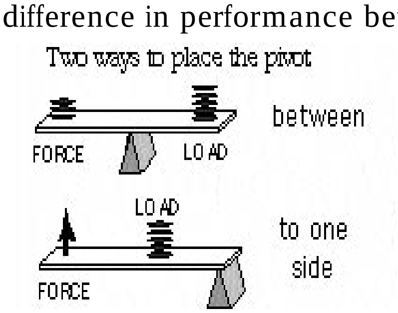
After exploring the beam balance, you need to build a real lever to lift your can the required distance. A lever needs a pivot, a beam, a way to connect the can to the beam, and a place to put the pivot.

• Use a cardboard box to build a pivot. Cut it so that you make a triangle as seen from the side, with a square base (look at the picture of see-saw on page 14 to get a picture of this).

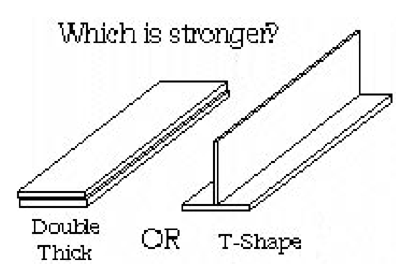
• Use the pegboard as the beam. You can make a pegboard longer by using a nut and bolt to connect two pieces of pegboard together. **OR**

• Use wooden yardsticks to make the beam. You can make this beam stronger by experimenting with the designs shown to the right.

• Experiment with where to place the pivot. Find out if there is any difference in performance between the two levers shown to the left.



• Finally, test and figure out where the can (Load) and string (Applied Force) should be placed to get the help from the lever that you need, so that it will also raise the can so that you meet the requirements of the challenge.

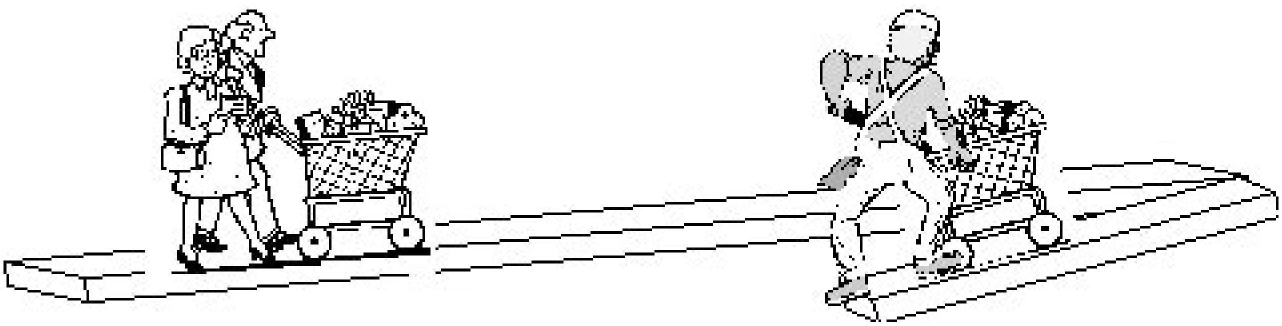


Mini-Experiment: Does the way you orient two slats of wood affect how much the beam you make bends?

Can-Lift Plan 2: Using

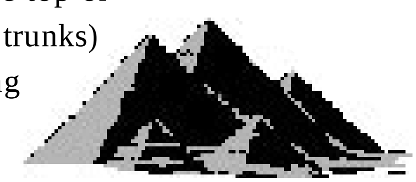
An Introduction to Ramps

A ramp can make lifting something heavy easier than lifting it directly up. How much a ramp, also called an inclined plane, helps depends on its slope. The steeper the slope, the shorter the distance an object needs to be pulled or pushed, but a longer ramp makes pushing or pulling easier. The man in overalls must apply more force to his cart than the elderly couple, but only travels a short distance. The elderly couple has an easier time pushing their cart up the gentle incline, but they have to push it farther. The shortest way to the top demands the maximum effort. As we make the distance longer, less effort is required. We say that there is <u>more advantage</u> when less effort is needed.



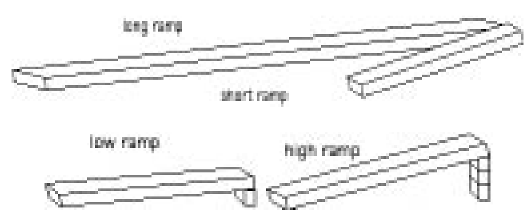
Lifting the Stones That Made the Pyramids

It is widely thought that the massive stones used to construct the pyramids in Giza, Egypt, were raised in place with the help of enormous ramps that led right up to the top of the structures. Sleds, levers, and rollers (probably made of whole tree trunks) helped reduce dragging friction as the millions of stones, each weighing about 22,000 Newtons (5,000 pounds) were trasnported up the ramps into the positions they hold today, some 3500 years later.



Decisions For You To Make When Designing Your Ramp

In designing your ramp, you have to make a few key design decisions: These include:



(1) how long to make the ramp;

(2) how high to make the ramp;

(3) what materials to make the ramp from; and,

(4) how to move the can up the ramp once the ramp is built.

When you present what you've learned to the rest of the class, your team needs to tell others what you decided about these design decisions, and backed these choices up by good reasons.

Ramps & Inclined Planes

Investigating Your Ramps & Inclined Planes

1. Collecting Cases of Ramps & Inclined Planes

Make drawings of at least three devices that use ramps or inclined planes to lift objects. Bring in an example of a device to show others, if this can be done safely and the item is small and not expensive. Tell how each works by showing with arrows the forces you think are at work in the devices. Be sure to include friction as a force at work when using ramps or inclined planes.

2. Messing About with the Ramp

After building your ramp, become familiar with it by using it to raise a can. Read the different ways you can use the ramp on pages 20-21. Be ready to report what you have learned from this phase of your investigation of ramps and inclined planes. Hint: If your string alone does not lift the can, you can keep adding strings until it does. Be ready to report your findings on raising the can to others.

3. Measuring the Ramp at Work

Using the single-cotton strand of string to find out whether your design works well enough to meet the challenge. If your string breaks, then tie more strings to your device until it does work. Repeat these observations. Be prepared to report your results, along with drawings of the device. (You might read ahead to take a look at the layout of a "how-it-works" drawing -- see pages 40-42.)

4. Finding Out What Features Affect Performance and Testing Them

The most important part of your investigation is to test features in your ramp that you think might make it work better. As mentioned on page 18, a ramp's key features to vary are: height of the ramp, length of the ramp, material the ramp is made of, and how to get the can up the ramp. Test the features you think will make a difference first. Also, you may want to change the design of the ramp entirely -- just watch your time if you do this.

Take new readings of your redesigned device using multiple strings, or using a force meter. Use repeated observations, and include these data in your "My Experiment" report for your Design Diary. Note any trends in these changes and report them as design rules-of-thumb for others to think about when they decide whether to use a ramp or inclined plane or not. Don't forget -- test one feature at a time! You might have to do multiple experiments, each with its own Design Diary page.

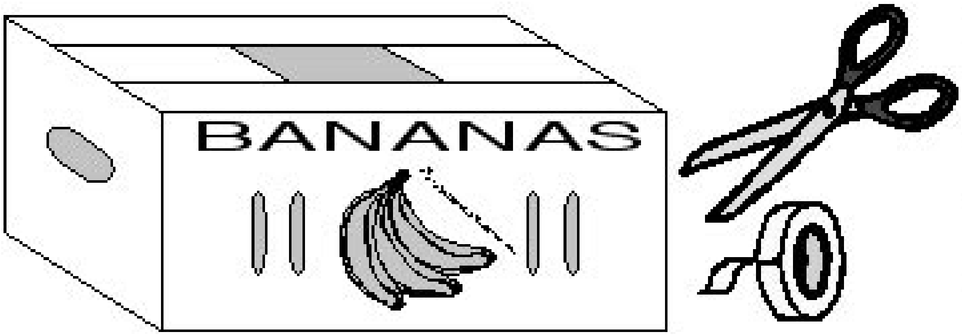
5. Can a "Wheels and Axles" Helper Help?

If you have time, look over the "Extra Helper Plan: Using Wheels and Axles" on pages 30-32. You might want to consider whether using a cart with your ramp would be of advantage. If you think it will, then budget some time to build one and test your idea.

Can-Lift Plan 2: Using

Materials and Steps for Constructing a Ramp

The following are easy-to-build instructions for making a ramp. The "main ingredient" needed for this type of ramp is an empty box, in good condition. A banana box is used as an example below, but any box that can support weight will do.



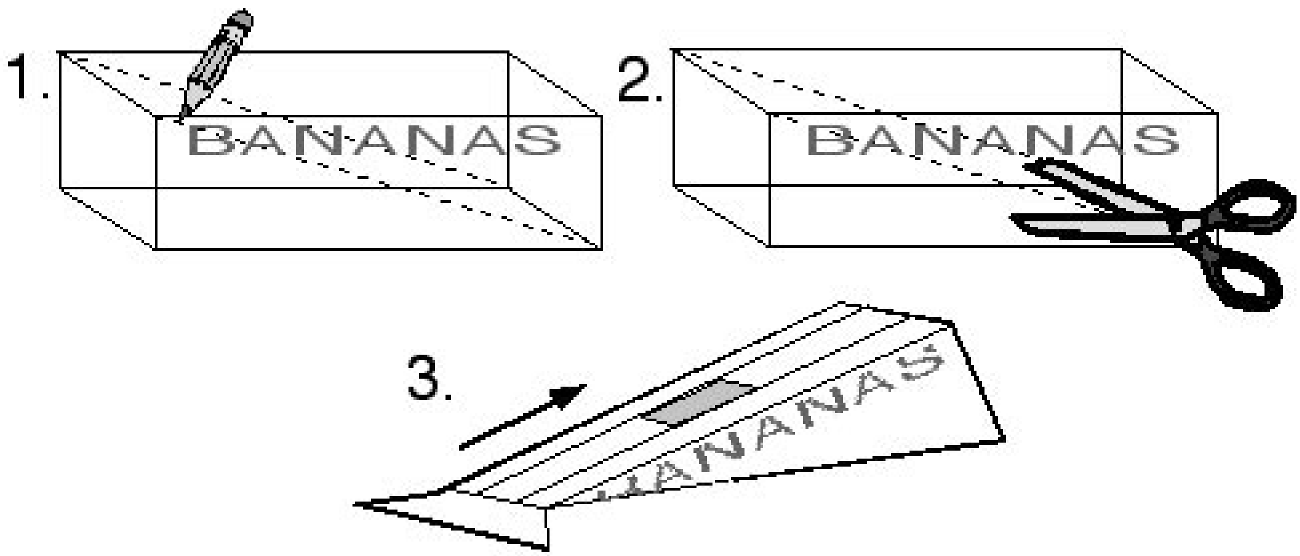
Materials

1 Banana box, top or bottom
1 Heavy-duty scissors, or utility knife
1 Roll masking or duct tape

(1) Draw a diagonal line on the long sides of the box top.

(2) With a pair of heavy duty scissors, utility knife or saber saw, cut along these lines on both of the box's sides. Tape the sides together as needed.

(3) You can leave the side flaps attached to the ramp, to provide the can with a smoother transition from the floor if you want. Or you can cut the flaps off so that the ramp ends at the floor. (Be sure to cover the hole on the ramp's surface with a manila folder.)



A Second Way to Build a Ramp

You can make a ramp pretty quickly using books and a board, or long piece of foamcore or cardboard. One end of the ramp is placed on top of a stack of books. You can vary the length of the ramp by cutting to the size you want. Vary the height of the ramp by the number of books you use. Look below for ideas on how you can make a ramp using these materials.

Ramps & Inclined Planes (cont.)

Exploring Ways to Get the Can Up the Ramp

Once you have built your ramp, you have a number of ways to move the can up it. Here are four for you to consider:

A. Slide the can up the ramp

B. Roll the can up the ramp

C. Attach the can to a platform and use rollers to move the can

D. Build a coaster car (See "Using Wheels & Axles", pages 30-32), tape the can to it, and give the can a ride up the ramp (remember that you will be allowed to pull the can only with the cotton string).

Details on the Four Ways to Move Your Can

A. Sliding the can up a ramp involves tying the cord to the can and then dragging the can up the slope of the ramp. The challenge is to have enough pull on the can to move it, but not enough to break the thread. Reducing drag on the ramp will help you do this – but what kind of ramp can you design to do this?

B. Rolling the can up the ramp can be tricky. One way is to tie one end of the cord to the top of the ramp. You then lay the cord down the slope and wrap the cord half way around can. Take the free end of the cord and return it to the top of the ramp. The can will roll up the ramp as you pull on the free end of the cord. You may want to use more than one cord so that the can stays on the ramp.

C. The Egyptians are said to have moved heavy stones for the Pyramids by using logs under the stone blocks as rollers. You could tape your can onto a flat piece of cardboard or foamcore and then put round pencils or pieces of the wooden dowel under the board. Tying the cord onto the board, and then pulling the board up the slope while keeping rollers under the board as it moves up the ramp will make moving the can easier.

D. If you have done the Learning by Design™ unit called *Vehicles in Motion*, then this should be an easy suggestion to explore. Follow the directions for building a coaster car that uses wheels and axles to make moving the can easier (pages 30-32). Of course, you can use your own design if you have a better one in mind.

In each of these suggestions, you will need to attach the thread to the cord in the way you think will best allow you to apply the most force to lifting the can.

Keep on the lookout for other ways to use the ramp in your design – other simple machines might be used along with a ramp to lower the force needed in raising the can.

Doing a Deadlift

In the Olympics, one activity that weightlifters do is called the deadlift. The rules of deadlifting are simple: you must raise a barbell up to your knees until your legs are locked and your shoulders back.

In the First Can-Lift Challenge, you are asked to lift a medium-sized tin can filled with food 10 cm with the help of a device you build. For the Second Challenge, you must lift a much larger can of food twice as far and do this all in 15 seconds. In both cases, the only force you can apply is through a single strand of cotton thread.

In this unit, you're being asked to build machines that help. But what if you don't need help? What if the thread you are asked to use can lift the can by itself, straight up? Before you proceed with building any lifting devices, you need to find out whether you can deadlift either or both cans with a thread alone. Is the thread strong enough to match and overcome the full force of gravity acting on the can when it pulls at the can straight up?

If you find that the string always breaks, then there is a second question to answer: By how much is the thin, weak thread too thin and too weak?

To answer this question, you will do an experiment to find out how many threads are needed to lift each can. Knowing this will tell you how much help the device you design and build must provide so that you can lift the cans with the little force a thread provides.

Weightlifter makes the grade in a deadlift attempt

With a Single Thread

Steps for tying loops at end of cord to attach to can.

Preparing the Cans for the Deadlift

A key technology question related to lifting the can with the thread is: How should the string get connected to the can? There are a number of ways to do this, but one way that is "legal" according to the rules of the Can-Lift Challenge is to tie and tape a strong cord around the can and then tie the thread to the cord. To do this, follow these steps:

1. Tie a knot with a small loop at one end of the cord (the loop should have the diameter of a penny).
2. Wrap the cord around the can and pass the free end of the cord through the end loop. This will make a lasso, fitted around the can.
3. Tighten the lasso around the can by hand, and hold the knot with your finger.
4. Use a 3-6 cm piece of duct tape and tape the cord and its lasso so that it remains tight against the can.
5. Tie a second knot on the free end of the cord so that a penny-sized loop forms at the end of the free end of the cord.
6. Tie a single strand of thread to the heavy loop and see if you can lift the middle-sized and the large cans straight up. What did you find?

Prepare the second can and test it in the same way as above.

Picture of large and medium-sized cans to be lifted. Note how tape keeps the cord in place on the larger can.

Question: How Much Help Is Enough?

If you find that the string always breaks with one or both cans, then there is a second question to answer: By how much is the thin, weak thread too thin and too weak?

Now experiment to find out how many threads are needed to lift each can. Knowing this will tell you how much help must the device you design and build provide so that you can lift the cans with the little force a thread provides.

Hint: Tie each strand with its own knot. Don't double the string, or make a U-shape through the loop at the end of the cord. You might want to start with lots of threads, and then use fewer and fewer until the you break the strings before the can is raised.

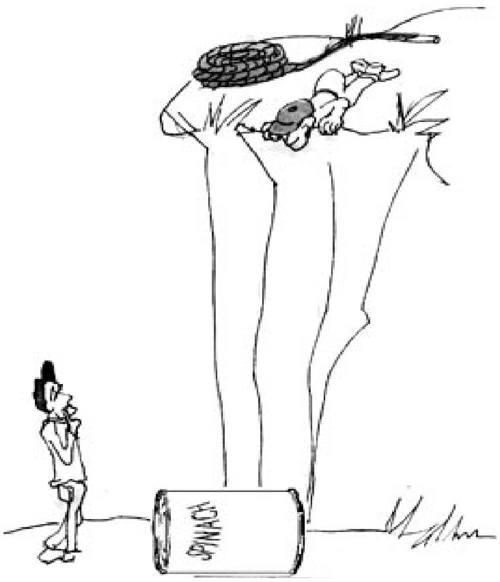
Be prepared to report how you did your mini-experiment. Use the "My Experiment" Design Diary page to do this. Finally, create a chart to display your data to your classmates.

The First Can-

The First Can-Lift Challenge

The Can-Lift challenge is a model of Cliff's situation. Where Cliff is trying to raise something heavy up a ridge, your model will be scaled down to a smaller height -- 10 centimeters (a bit less than 4 inches). Instead of Cliff's weak rope, you will use a single, thin strand of cotton thread to raise the can. As in Cliff's situation, and as you have now found out on your own, the thread will not be strong enough to lift the can directly – you'll need to design a device that helps Cliff!

To learn the science and of simple machines and how they can help in this situation, you'll investigate by building one of four different devices. You can elect also to use a "helper" device (Wheels & Axles) along with your main device. Choose one of the four devices, build it, investigate how it works, and then report to others what you have learned.



Read about the plans for the four devices and the helper device on these pages:

A Picture of What You'll Make

One way to see how this challenge works and what you will make is shown to the right. What you will be building is behind the cloud.

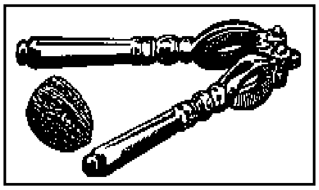
Notice that your hand can only touch the single strand of thread in getting the machine to do its job!! It will be attached to the device. Notice as well that you can attach the can to your device with any material you want. You can use much stronger cord, or tape -- you'll have many strong materials to do this. The table to the right shows Cliff's real-world situation in the left-hand column, and the model you will be making in the right-hand column.

Rope	String
Barrel of Food	Large Can of Juice
10 meter ledge	10 cm rise

Lift Challenge

Homework: Doing With and Without Machines What would the world be like if we did everything by hand, without even the simple devices? How much do these devices help us?
Find out by doing some everyday tasks, with and without the help of devices. First try to crack a nut between two boards or other item to protect your hand. Then use a nutcracker. Next remove a bolt first by hand, and then with a wrench. Estimate how much harder one way is over the other.

TASK by Hand | TASK by Machine | TASK by Hand | TASK by Machine



Cracking nuts by hand, with nutcracker or C-clamp

Remove a bolt with a socket and socket wrench

2. Most people are not aware just how many simple machines surround them. Look carefully at the pictures below and list all of the simple machines you see. You can use the picture's coordinates to tell where you located the item on the photo (Example: There is a tree at A6.)

1 2 3 4 5 6

A
B
C
D

3. Bring in a picture from a magazine or newspaper (not someone's book!) or even a photo you have taken that shows a number of simple machines. Other classmates will then try to find machines in it as future homework activity or quiz question.

Addressing the First

Choosing and Building Your First Can-Lift Device

For the First Challenge of this unit, you will build a device that can help you lift a heavy load up 10 cm with only a very small force. Unlike other LBD™ units, you will be given a choice of one of four designs to construct, "mess about" with, and then investigate. Each device uses different materials, which your teacher will provide you with, and you'll be given hints on how to investigate what you are building.

By the end of Section One, you should know about what are called the basic "simple machines" and how they might be used in addressing both the First and Second Can-Lift Challenges. You will also begin writing a case-study report on your own design for the model challenge, and use what you learn in writing recommendations for a real challenge by the end of *Machines That Help (MTH).*

You've just finished reading the challenge and have done your first investigation of trying to raise the middle-sized can with a string, but without the help of any device. Here are the remaining steps you will be doing to complete Section One of *MTH*.

1. **Write Product Specifications** -- Write down specific ideas of what your device must do to be a successful design. Enter this into the Design Diary page entitled, "Product Specifications".

2. **Whiteboarding** -- Your class will write down facts already known, questions needing answers, and so on, based on reading of the design challenge in a whiteboarding session. Put this work in the "My Whiteboarding Summary" page of your Design Diary.

3. **Choose and Build a Plan for the First Can-Lift Challenge** -- You will read about, choose and then build one of four devices for the First Can-Lift Challenges.

4. **Investigate The Device You Built** -- After completing your device, you will "mess about" with what you have made, improve how it you made it and how it works, and then conduct experiments to find out what features make a difference in it raising the can.

5. **Gallery Walk** -- Each team will give a short talk on its device's performance. This first gallery walk should include:
   - sketches of the various designs you considered;
   - data from your initial tests;
   - design rules of thumb you discover and offer to others; and,
   - plans and sketches for your future investigations and new designs.

If your device doesn't raise the can with a single string, don't worry about it. Show the class what you tried and explain why you attempted those things. You'll have another chance in a few days.

Can-Lift Challenge

6. Whiteboarding -- Focus on, "What do we need to learn more about?" to do the First Can-Lift Challenge. Include what everyone has learned from their investigations in this session.

7. Trade-offs and Simple Machines -- Having made your First Can-Lift device, you will learn about how these devices can help, but with some drawbacks or trade-offs. You will be given and use a formula that will help you say what the benefits and trade-offs of different machines that help. For homework, you will try to find other examples of these kinds of devices, and tell what the trade-offs are from using the devices.

8. Writing a Case Study of Your Can-Lift Device -- After doing your investigation and learning about trade-offs, you will do something designers do all the time -- write a case study of a simple machine that you made. These pages will be collected into a class case book for others to use.

9. Making How-It-Works Drawings -- To make a better case-study report, you will learn about making illustrations that you will need to include in your do final Case-Study Report. For homework, you will look for examples of these kinds of drawings around the home.

10. Do Second Attempt at the First Can-Lift Challenge -- After collecting ideas from your walks and writing cases that include illustrations, you may have a planning session to improve and build your First Can-Lift device. Before starting this work, you might want to review the "Product Specifications" Diary page, so that all members of your team work towards the same goals.

11. Gallery Walk and Whiteboarding -- After your second design session, you may do a pin-up or conduct a gallery walk, where you will talk about and demonstrate new design ideas, and follow this with a whiteboarding session.

12. Review and Summing Up -- You will probably have some questions and a quiz at the end of the unit to help you assess how well you understand the materials. This may be another good time for writing ideas in the Design Diary's "Lessons Learned" page.

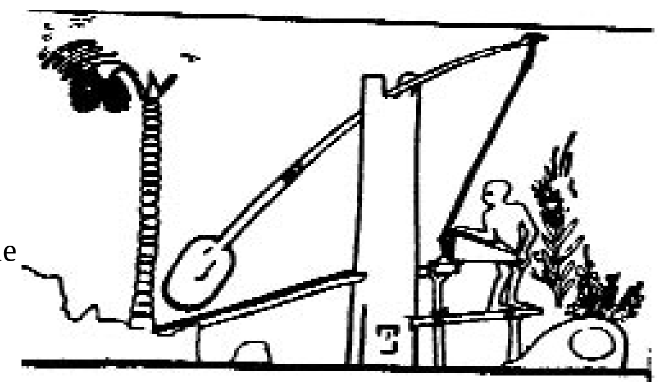
Can-Lift Plan 1:

An Introduction to Levers

As a young child, you probably played on a playground device that does some lifting and is based on the beam balance -- the common see-saw. A see-saw is an example of a first-class lever. By changing its use slightly, a see-saw can be used to lift heavy things. In your investigation, you'll begin to understand the science behind how they work, enough to know how to design such a device.

Lifting Water with the Egyptian Shadouf

In the ancient world, getting water to drink or irrigate with took much effort. The device from Egypt called the shadouf could move water from a river to a farmer's fields, or from a well to a pot. It uses a long pole with a water bucket on one end and a counter-weight on the other. A raised timber supports the pole and acts as a pivot. The system acts like a balanced seesaw, making raising water much easier.



Lever Facts

Look at the following drawings to see the difference between the three types of levers. Also note that all levers have three parts:

• • a pivot or fulcrum around which the beam or arm of the lever moves;

• • an applied force, where force is given to the machine; and

• • a load, which is where the machine applies a force to an object.

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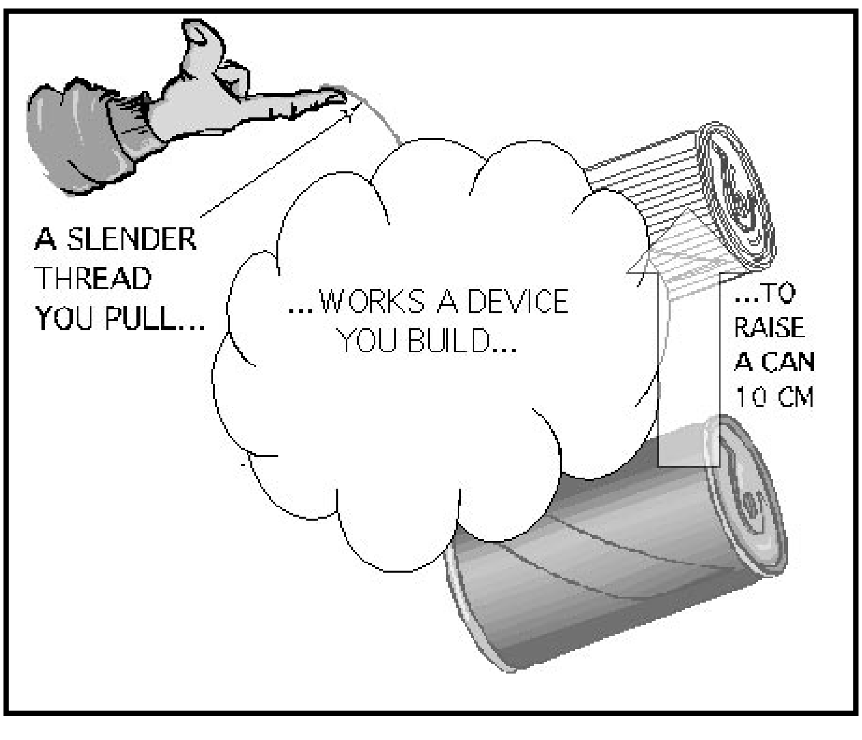
Machines That Help
Section 1
Making Devices That Help You Lift Heavy Things

Your challenge is to build a model device that can lift a medium-sized can of juice 10 centimeters with the force you can apply through a strand of cotton thread.



Things That Help

Needing Help To Lift Something Heavy

People need to lift heavy things all the time. Around school, you may have to carry lots of books around. After school, you might work at a job where you move heavy boxes around. If you got hurt in sports, you might find yourself unable to do things you used to find easy to do. Lots of different people need help in lifting heavy things.

The main activity of *Machines That Help* is a modeling task named the "Can-Lift Challenge." For it, you will design and build models of devices that lift heavy loads a short distance upwards in a certain period of time with very little force. A large can of juice or food will represent a heavy object that needs lifting. To imitate a person who lacks the strength to do the lifting, you will only be allowed to apply force through a single, thin strand of cotton thread. You will attach this thread to your device. You attach the can to your device using strong cord, tape, or whatever else you would want.

After learning from designing and building models of devices that lift heavy things, you will give advice on a lifting challenge found in the real world.

At the end of this unit, you will write two reports. One will summarize the history of how you solved the Can-Lift Challenge. The second will be a design brief for a device for one of the following groups who often need help lifting heavy things:

(a) an elderly person at home;
(b) someone with limited strength;
(c) a teenager in the workplace; or
(d) people in a village with no electricity or devices.

Here is some more information about these four kinds of situations of people. Choose one and keep it in mind while you work though this unit. What you learn during construction, and what you write in your Design Diary, will help you in writing your final reports and in preparing your design brief.

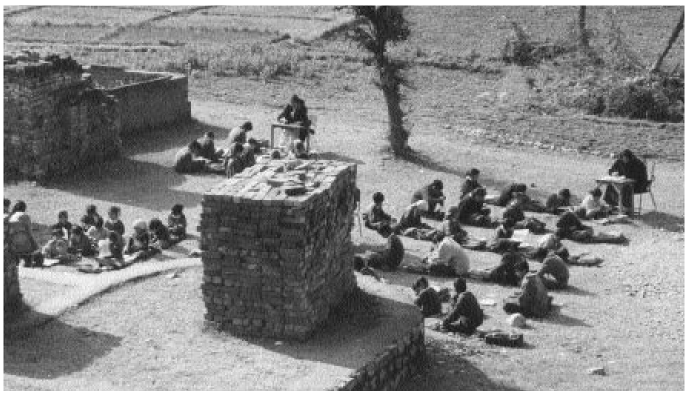
Helping Lift Heavy Things at Home

As people get older, they get weaker in muscle strength. Seniors often need help lifting heavy things, like bags of groceries or heavy boxes, to get them into or out of the house, or in and out of cabinets. What can a person who is 75 or 85 do to lift something that is too heavy for them to lift safely? They can ask others for help, but what if they need help daily? What they really need is for someone to design a device that helps them lift up a box of groceries, books, or other items, using limited strength.

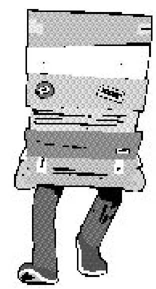
Make Lifting Easier

People from a Village Without Electricity or Tools -- These children live in India, a country with a billion people in it. Some live in real poverty, and live in villages where electricity often is turned off, and where complex tools are scarce. What sorts of devices could these people use to help them with the heavy things that they carry?

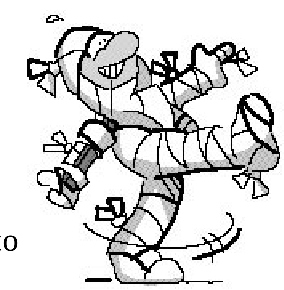
Below is a photograph of school children in a village in northern India that received materials for building a school, but no money to construct it. Can you design a device that would be inexpensive to build, which could help raise 10 bricks at a time up 10 meters in height? The device would be used by construction crews that will complete construction of the school.



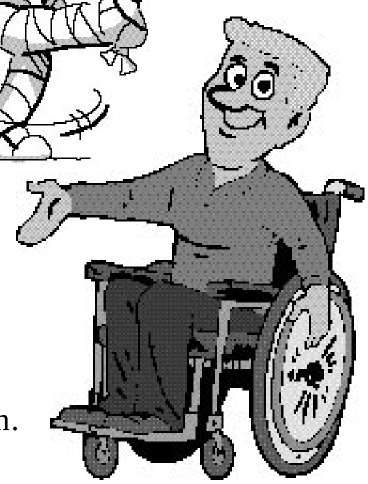
Teenager in the Workplace -- In the world of after-school work, there is much lifting, pushing, and carrying heavy things around. You will need to explore a job you have or someone you know has, and figure out a task that could use a machine to help make the work easier.



Someone With Limited Strength



Injuries — Some people have limited strength because of injury or disease, which cause them to have little ability to lift heavy things. Devices designed for these special needs can allow people to get do things they otherwise could not do.



Strength Limits — People have different limits of strength. The forces they use to lift vary. Kids and some women are less strong than adult men.

Introducing the

Helping Cliff with a Lift

The man pictured to the left is named Cliff. He is peering over the edge of a steep ledge. Cliff wants to use some rope he has with him to retrieve a large drum of food that is 10 meters below him. His rope, however, is not strong enough to raise the heavy container directly, and it's too short.

Cliff has some building materials in his truck. He thinks he might be able to use them to build a device and connect it to one end of his rope. He could attach another stronger rope to the can to raise it. Still, he needs the help of an advisor – you – to figure out what exactly to build.

Your task is to advise Cliff about what to lift the drum to the top of the cliff. It's the "Cliff Challenge."

The Can-Lift Challenge

To learn what you need to know to help Cliff, you will design and build a *scaled-down model of a device* that could help him. What you build will need to lift a smaller but heavy load up a certain distance with very little force. Actually, you'll do the Can-Lift challenge in two parts:

- For Section One, you'll be given plans for building four devices. You'll choose one of them to raise a medium-sized can of juice or food up 10 cm, and build it according to instructions. Then you'll then investigate it in depth and learn how the device -- called a simple machine -- works. Near the end, you'll improve its design and report to others what you've learned about the device.

- For Section Two, as you get better at making devices that lift heavy things, you'll be asked to lift a larger can of food twice as high (20 cm) and to get it done in a certain period of time, 15 seconds. To do this, you will combine design ideas to make the best device possible.

In both cases, you mimic the key constraint of Cliff's weak rope by applying a force with your hand to the device through a single strand of cotton thread. You can connect anything from the device you build to the can, but you can only use a single thread to make your device do its work.

As usual with Learning By Design™, you'll do whiteboarding, pin-up and gallery walk sessions while redesigning your model so that it raises a heavy load via the force you can apply through a single, thin strand of thread. You'll record your on-going work in your Design Diaries. These Diary pages will help you in writing a case history of how you designed your lifting device.

Can-Lift Challenge

Content Objectives of the Unit

In *Machines That Help*, you will be learning and applying key science and technology ideas related to how simple machines work and help people do things they otherwise could not do. Here are some key questions you should be able to answer well by the end of the unit:

- What are the five different classes of simple machines and what are examples of each?
- What is mechanical advantage and how do you calculate it?
- What is torque, work, center of mass, pivot, leverage, applied force and load?

You will also get better at several skills you used in earlier units and begin learning some other new skills (listed **in bold**, below).

Science Skills:

- Designing "fair test" experiments
- Conducting your own investigations
- **Calculating the mechanical advantage of simple devices**
- **Understanding the science ideas behind how simple machines work**

Collaboration and Communication:

- Designing and learning with a design team
- **Making "how-things-work" diagrams**
- **Writing case studies and product comparisons of simple machines**

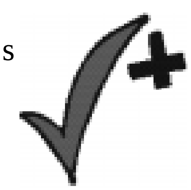
Design and Technology Skills:

- Combine subsystems in a more complex mechanical device
- Using Design Diaries to write up a case study of your design process
- **Create design rules of thumb based on experiments you conduct**

Decision Making Skills:

- Justifying design decisions with ideas from science and explanations
- Using design rules of thumb and cases to make design decisions

Assessment of Group and Individual Work



Your individual work will be assessed based on many items, including homework, quizzes and tests. Remember that part of your work is done with your team. Your teacher will assess your group work, based on how well your group managed a long-term project, and worked cooperatively. Your group's presentations will be assessed based on six main items:

- use of science ideas
- clarity and quality of presentations
- data collected on device's performance show good experimental planning and technique
- device meeting minimum performance standards (object raised 40 cm in 10 seconds)
- evidence of using and understanding LBD Cycle
- calculation of mechanical advantage the first and last "Can-Lift" designs