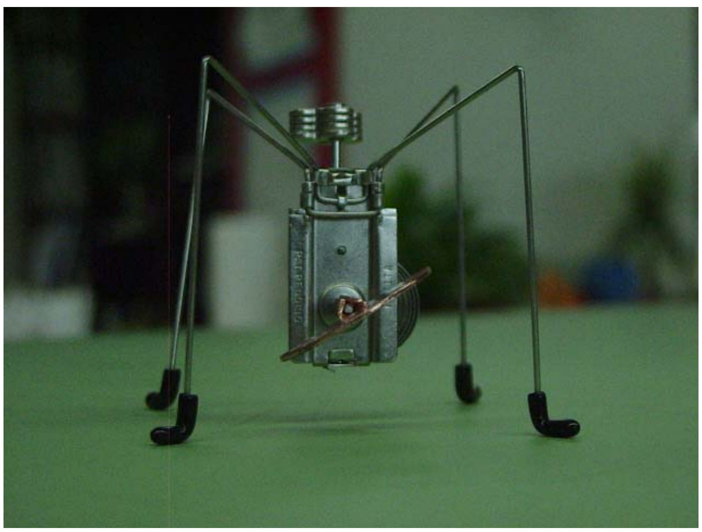
Mechanisms & Other Systems

Summary of Key Concepts

Mechanisms are devices that convert one type of motion to another. To use a tube of lipstick or a glue stick, you have to turn a knob. When you do so, the lipstick or glue comes straight out the other end. Inside of each device, there is a mechanism that takes the motion you supply, the **input**, and transforms it into the motion you want, the **output**. The two motions are different. The input motion travels around in a circle and is at one end of the glue or lipstick case. The output motion travels in a straight line, and is at the other end. Some common characteristics of mechanisms are that they all have moving parts, and the input is distinct from the output.



Many mechanisms are designed to produce more force at the output than is required at the input. This is true of a pair of nail clippers. A small amount of force at the input manages to produce a much larger force at the output – enough to cut through a resistant big toe nail! However, this big gain in force does not come for free. You have to move the handle through a much bigger distance, compared with the tiny movement of the jaws. This is a characteristic of all mechanisms: the larger the force, the less the distance traveled, and vice versa.

All mechanisms depend on a few basic principles, and the most important of these is the **Principle of the Lever**. It is possible to lift a heavy object, like a desk, by putting the end of a long board under it. Near the desk end, rest the board on a solid support that allows it to rotate. Then a small amount of force on the other end of the board will be sufficient to lift the desk. The board itself is a **lever**, and the pivot it rests on is called a **fulcrum**. The point where you apply the force is called the **effort**, which is just another word for input. The effect of applying this force, lifting the desk, is called the **load**, which is also called the output.

Many books give the impression that the fulcrum of a lever is always somewhere in the middle, which is the case for a **first-class lever**, but there are two other arrangements that are equally possible. In these the fulcrum is at one end, and either the load or the effort is in the middle. A **second-class lever**, such as a garlic press or a wheelbarrow, has the *load* in the middle. In a **third-class lever**, like a pair of tweezers or a staple remover, the *effort* is in the middle.

By looking at the load and effort arms, it becomes clear that the mechanical advantage of a second-class lever is always more than one, but for a third-class lever it is always less than one. Third-class levers are used to increase the *distance* traveled by the load, relative to the effort, rather than the *force*. The most familiar example is the human forearm. Some mechanisms include more than one lever, and use one lever to operate another. These are called **compound levers** or **linkages**. Examples include the nail clippers, vise grips, adjustable desk lamp, pedal-operated wastebasket, and umbrella. Because they have multiple parts working together, they are all examples of **systems**. A good way to understand a system is to make a **model** of it. A model has some essential features of the original, but omits others. For example, a cardboard model of a scissors might move like a real scissors, but be unable to cut.

The lever is often useful because the effort moves a lot more than the load, and therefore requires a lot less force. The amount of movement at each end is proportional to its distance from the fulcrum. The **load arm** and the **effort arm** are the special names given to the distances from the fulcrum to the load and effort, respectively. Using these definitions, the **Law of the Lever** is simply:

Load arm x load force = effort arm x effort force

Force times distance is energy, so this law says that the energy input equals the energy output; in other words, the energy doesn't change between the input and output. It is an example of the Law of Conservation of Energy. Using a little algebra, the Law of the Lever is equivalent to:

$$\frac{\text{load force}}{\text{effort force}} = \frac{\text{effort arm}}{\text{load arm}}$$

In other words, the lifting force is bigger than the effort in the same proportion as the effort arm is longer than the load arm. This ratio is so important that it is given a special name: **mechanical advantage**. A pair of nail clippers has a large mechanical advantage, because the end of its handle is so far from the fulcrum.

Science books usually identify six **simple machines**: the lever, wheel-and-axle, pulley, inclined plane, wedge and screw. Two of these – the wheel-and- axle and the pulley – are really examples of the lever. A **wheel-and-axle**, used to drive a car, is a third-class lever, because the outside of the axle, which supplies the effort, is in between the fulcrum and the load. A **pulley**, used to lift a weight, is a first-class lever, in which the fulcrum is at the center of the pulley, in between the effort and the load. Two of the other three simple machines– the wedge and the screw – are examples of the third – the

inclined plane. A **wedge** is a double-sided inclined plane, while a **screw** is an inclined plane wound around a cylinder or cone. The lever and the inclined plane are really the basis for all mechanisms.

Pre-Workshop Scavenger Hunt

Ask participants bring in any mechanisms they consider interesting or unusual.

Workshop Materials

- Collection of mechanisms, including first- second-and third-class levers, as well as compound types. First-class levers include scissors, pliers, and hole punchers. Common second-class levers are nutcrackers, garlic presses, and crank handles. Examples of third-class levers are tweezers, salad tongs and staple removers. Compound levers include vise grips, nail clippers, teabag strainers, and tin snips. See photo in Materials List for Introductory Workshop.
- Thin squares (about 10" x 10") and strips (about 2" x 10"), cut from shirt cardboard, pizza boxes, file folders, priority or overnight express mail envelopes, or other cardboard of comparable thickness
- Rubber bands, scissors and hole punchers
- Overhead transparencies and markers (if projector is available)
- Mystery mechanisms: see the Mystery Mechanisms Construction Guide (next page) for instructions on how to make these from cardboard and paper fasteners. Tape a piece of cardboard or a file folder over both front and back of each mechanism, so only the input and output are visible.
- Copies of Lever Class Worksheet, Compound Lever Worksheet and Lever Representation Worksheet (three pages following Mystery Mechanisms Construction Guide on the next page)

Mystery Mechanisms Construction Guide

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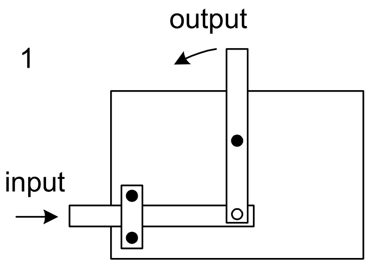

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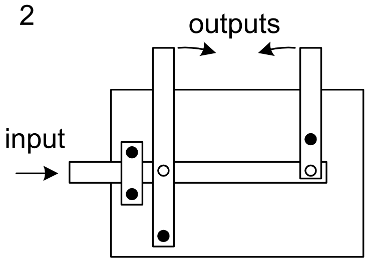

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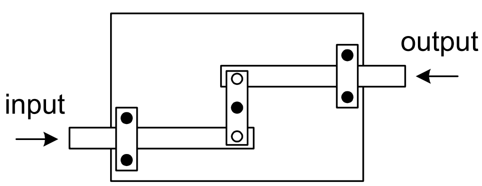

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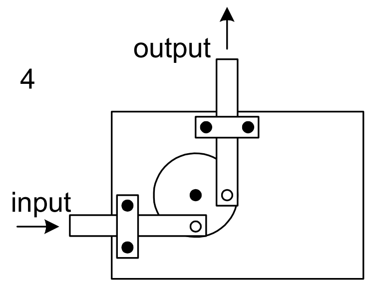

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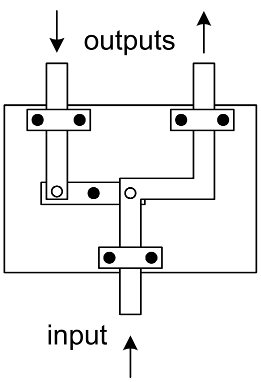

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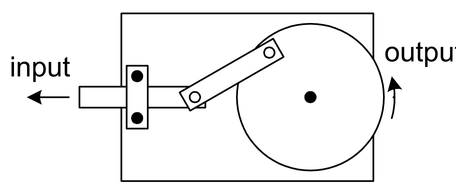
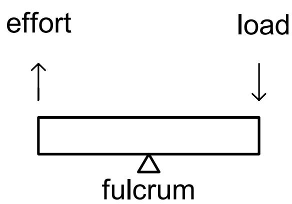
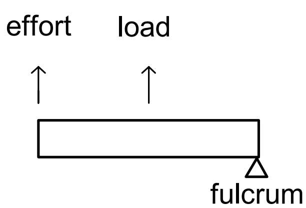
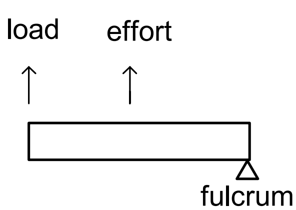


Key

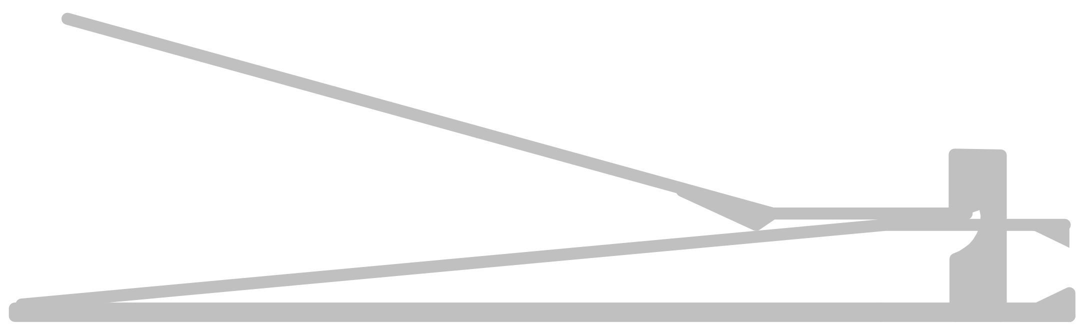
- ● Fixed pivot (attaches link to base)
- ○ Floating pivot (attaches link to link)
- [●—●] Guide (maintains straight-line motion)

Lever Class Worksheet

List the levers you found from each class:
1st Class 
2nd Class 
3rd Class 
Not sure ?

Compound Lever Worksheet

1. Identify each lever, and draw an outline around it. Use a different color for each one. Then find the effort, fulcrum and load of each lever, and determine its class.



2. Draw another compound lever, and repeat #1

Lever Representation Worksheet

How could you represent your sorting of levers according to class, including compound levers that have more than one class? Sketch your method below, showing a few of the levers you've classified:

Directions to Participants

The following five pages provide a set of instructions for the workshop activities, suitable for copying to transparency films, PowerPoint slides, or chart paper, for use during the workshop.

1. Scavenger Hunt & Brainstorming

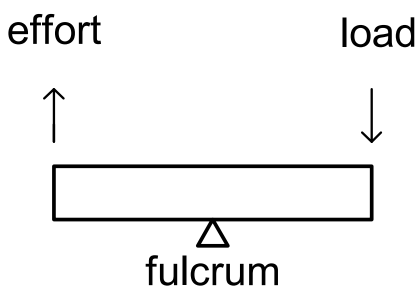
- Look at the mechanisms on your table. Add any others you have brought with you.
- Examine these devices carefully. Make a list of the features they have in common.

2. Guess my Categories!

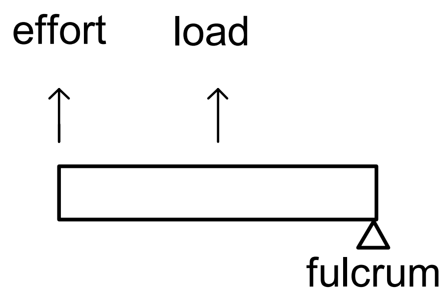
- Examine your devices. Decide on a few categories for classifying them.
- Sort your devices into piles according to your categories. DO NOT REVEAL THE CATEGORIES TO ANYONE OUTSIDE YOUR GROUP.
- The others will have to guess your "SECRET CATEGORIES"!

3. Levers have a lot of Class

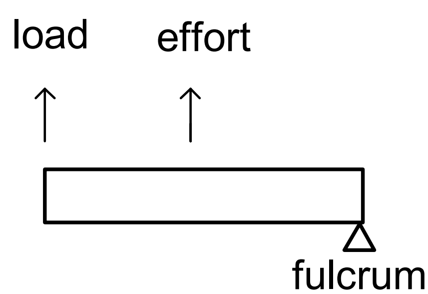
1st Class



2nd Class



3rd Class



Sort your mechanisms according to 1st, 2nd and 3rd class levers. Use the Lever Class Worksheet to list the devices in each class.

4. Compound Levers

- Examine the nail clippers closely. Use the Compound Lever Worksheet to identify the levers it includes, and show the fulcrum, effort and load of each lever. What is the CLASS of each lever?
- Select another compound lever. On the worksheet, draw the device. Show each lever in a different color, and identify the fulcrum, effort and load of each one.
- Design a method to include compound levers of more than one class in your lever sorting scheme. Use the Lever Representation Worksheet to show your method.

5. Mystery Mechanisms

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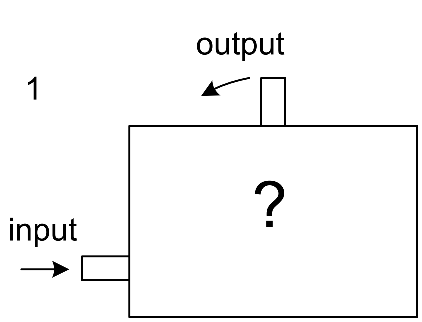

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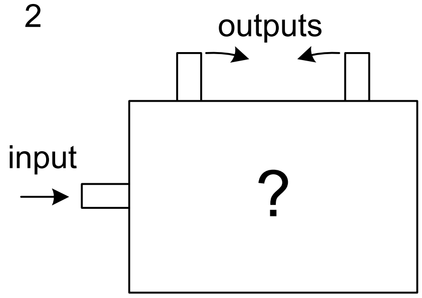

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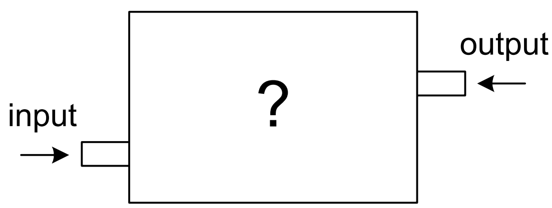

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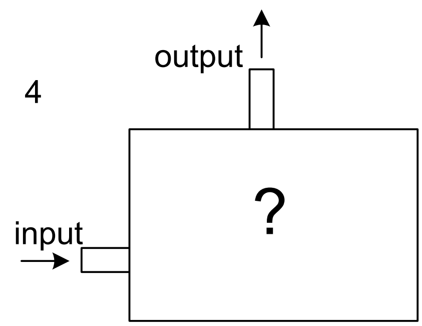

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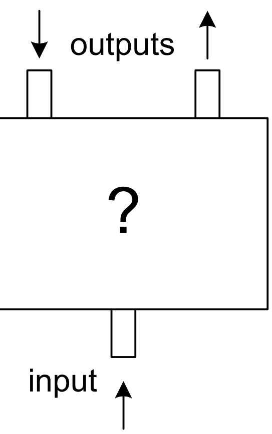

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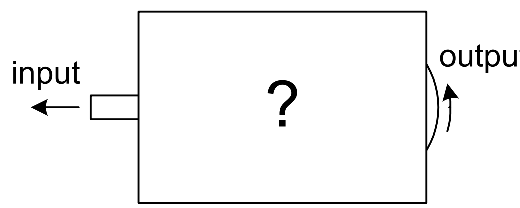


Sample Workshop Agenda

Introductions (10 minutes)

Scavenger Hunt & Brainstorming (20 minutes)

Provide each group with a few mechanisms, and ask the participants to find as many more as they can, either in the room, or from among their personal effects. Then ask them to look carefully at these devices, and determine the characteristics they share in common. See Activities #1 & #2 in Mechanisms.

Sorting: Guess my Categories! (30 minutes)

Collect all of the sample mechanisms, including those found during the scavenger hunt, and any that were brought in from the pre-workshop activity. Include the linkages and compound levers (see "Workshop Materials"). For any mechanism that can't be removed, such as a doorknob, window latch or pencil sharpener, they can write the name of the mechanism on an index card. Provide each group with at least half a dozen of these items. They are to sort their devices according to categories they determine, but do not reveal to the other groups. Once they have done this, another group should visit their table and try to determine the basis for their categories. After each group has revealed their categories, repeat this activity, encouraging each group to come up with different and more interesting categories. Activity #4 is the basis for this work.

Analysis 1: Levers have a lot of Class (20 minutes)

Describe the basic parts of a lever -- fulcrum, effort and load -- using as examples the mechanisms already examined. Then describe first-, second- and third-class levers. A reference chart, showing the three classes of lever, is included in "Directions to Participants". Provide examples of each class from the collection of mechanisms, for example: a one-hole punch and a scissors (First Class); a nutcracker and a garlic press (Second Class); a staple remover and a pair of tweezers (Third Class). See also pp. 45-46 of Mechanisms.

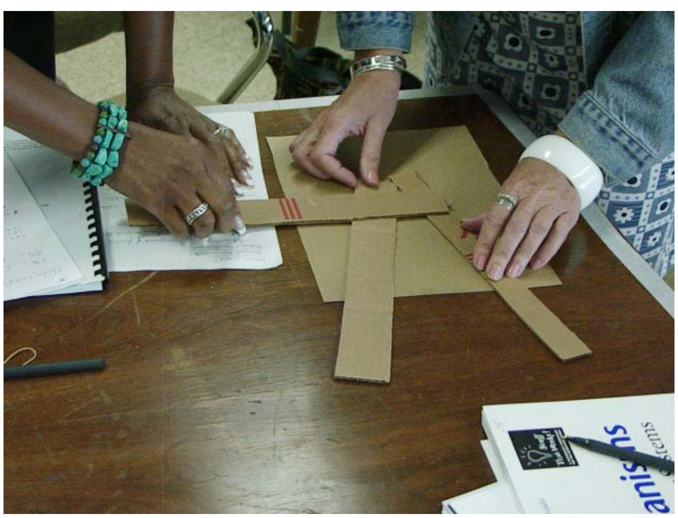
Ask each group to sort their mechanisms according to lever class. Introduce the terms input, output, and range of motion. They will need to identify and perhaps draw the effort, fulcrum and load, and determine whether these are arranged as a first second or third class lever. The Lever Class Worksheet should be used to record the results.

Analysis 2: Compound Levers (40 minutes)

In the first Analysis activity, some devices should be included that have more than one lever. Rotary can openers fall into this category, because they each have two independent levers, the arm that punches the hole in the can and the handle that turns the little wheel. The more interesting devices are *compound levers*, in which the output of one lever is the input to the next. Examples include a pair of nail clippers, tin snips, teabag strainer or vise grip. It is not so easy to classify these. Participants will need to identify *each* lever, and determine its class separately. The Compound Lever Worksheet is a good place to start, because it already shows a drawing of a nail clipper, and asks them to identify each lever, the fulcrum, effort and load of each, and its class. It consists of a second-class lever (the handle) operating a third-class lever (the upper jaw). Another problem is how to represent the compound levers in the sorting lists of first-, second- and third-class levers. A device having both a second- and a third-class lever does not fit neatly in either category. The Lever Representation Worksheet encourages participants to come up with a way to solve this problem.

Each small group must then present its findings to the entire group. Activities #5, #6 and #7 provide the basis for this activity.

Design: Mystery Mechanisms (60 minutes)



Provide each group with a pair of scissors, a hole punch, paper fasteners, rubber bands, cardboard strips and squares. Present the mystery mechanisms you have made, with only the inputs and outputs showing. Their task is to create a mechanism that transforms the inputs into the outputs – in other words, the hidden innards of the mystery mechanism. In testing their model they can ask the following questions:

- ❑ Are the directions of motion of the inputs and outputs the same in the model as in the original?
- ❑ Is the range of motion similar in both?
- ❑ If the device returns to its original position when released, does the model do so too?

See Activity #9 in Mechanisms.

Sharing (10 min.)

Encourage participants to reflect on how they feel these activities would work in their classrooms, including modifications and changes they would make.

Workshop Tips and Strategies

Workshop Preparation

Collect as many mechanisms as you can find. Pp. 7-8 of Mechanisms and the City Technology web site, http://citytechnology.ccny.cuny.edu/Design_Mech.html, display a variety of common ones. Avoid the more complex devices, such as tape players and typewriters. You will also need to include some compound levers or linkages, for the first analysis activity. These are devices consisting of at least two levers, with one operating another. Examples are the folding chair, ironing board, nail clipper, vise grip, bicycle hand brake assembly, umbrella, tin snips, garden shears, pedal-operated wastebasket, pop-up book or card.

You will also need to collect and cut some cardboard, about two or three squares per group and six or eight strips. The most useful grade of cardboard for modeling is thin, with no corrugated layer, but stiffer than construction paper. Examples are shirt cardboard, file folders, Priority or overnight mail envelopes, oak tag, and pizza boxes.

Use these cardboard and brass paper fasteners to make the Mystery Mechanisms shown under “Workshop Materials”.

Brainstorming & Scavenger Hunt

Some participants may ask you to define exactly you mean by “a mechanism.” Defer answering this question until they have come up with some examples of things they might consider mechanisms.

Some mechanisms you can find in nearly any room are doors, doorknobs, locks, light switches, window latches, radiator valve knobs, folding tables or chairs. Office areas usually feature pencil sharpeners, staplers, staple removers, clipboards, binder clips, self-inking rubber stamps, and adjustable-arm desk lamps. In people’s clothing, handbags and briefcases, there are ballpoint pens, lipstick cases, safety pins, buckles, latches, and zippers. The human body includes numerous mechanisms, such as the upper arm, forearm, hand, fingers and thumb. As teachers collect items they think might be mechanisms, don’t express an opinion about whether any particular item really qualifies.

Once some devices have been identified that could be mechanisms, ask them to look for common features of these devices. Some focusing questions are:

- What do you have to do to operate it, and where on the device do you do this?
- What is the job it is intended for, and where on the device does this action occur?
- What happens between the point where you operate it, and the place where it does its job?

A reasonable conclusion is that a mechanism is a device that has visibly moving parts, and whose output is in a different place, and executes a different motion, from its input. Note that the first of these criteria excludes an electric circuit, whose only moving “parts” are electrons. The second rules out most push button switches, or a stick used to dislodge an item from a shelf, where the part you operate (“input”) is just an extension of the part that does the required job (“output”).

Sorting

Encourage the groups to select categories that are fundamental, such as type of motion, type of lever, or purpose; rather than superficial, such as color or type of material. As groups come up with different ways of sorting, you can highlight how their methods reflect different ways of thinking. For example, a group may come up with “Things that turn in a complete circle,” “Things that turn in a partial circle (arc),” and “Things that move in a straight line.” These are geometric categories. On the other hand, first-, second- and third-class levers, referring to the arrangement of the effort, fulcrum, and load, come under the general domain of science, because these categories focus on the underlying elements. Functional categories, such as, “things that grab,” “things that squeeze,” and “things that cut,” reflect a technology viewpoint, because they look at the purpose of the device. See p. 12 of Mechanisms.

Analysis 1

In presenting this activity, it is useful to spend a few minutes outlining some of the basic concepts, using some of the sample mechanisms as examples (see "Summary of Key Concepts"). Generally, teachers find it fairly easy to identify inputs and outputs. Some will claim that they can't draw, but they can always trace them if necessary. Attempting to draw the mechanism forces one to look at it more carefully, and notice details that would otherwise be missed. If an overhead projector is available, provide transparency films and markers, and suggest that they present their drawings on the projector. The mechanisms themselves can be placed on the projector too, and operated there. The movement will appear magnified in silhouette on the screen.

Analysis 2

It is not so easy to find all of the levers in a compound device, and determining the class of each one. Suggest that they begin by holding one of the inputs steady, thereby isolating it from the moving parts. This will make it much easier to identify the remaining levers. It is helpful to outline each lever in a different color. For each one that they find, ask them to point out the effort, the fulcrum and the load, and label these in the same color on the diagram. Where one lever operates another, such as the handle of a nail clipper, which makes the upper jaw move, the load of the first becomes the effort of the second. (See P.47 of Mechanisms, especially Fig. 2-15.) The fulcrum is the pivot that the lever rotates around. Once the effort, fulcrum, and load of a lever are known, the teachers can compare their arrangement to the three classes on the reference chart, and determine the class of the lever they have found. Note that links with pivots at either end may not be levers at all, but simply connecting bars for keeping things in position.

The representation problem – how to show compound levers on the sorting list -- can be solved in a number of ways. Some participants may think of using a Venn diagram, showing a compound lever in the intersection between two lever classes, while others may prefer to use a grid, or simply a separate list of "Compound Levers." If time permits, it is useful to compare these approaches.

Design

Some teachers find the mystery mechanisms to be a major challenge; many children find them much easier to figure out. Mechanisms #1 through #6, in the "Directions to Participants", are arranged roughly in order of difficulty from easiest to hardest. Those who have done the Mechanisms activity of the Introductory Workshop may have already completed #1 and #2. Some participants will want to begin with the easiest, and gradually work their way through; while others may want to tackle the harder ones immediately. If teachers get stuck, a useful strategy is to refer them to the reference chart showing how the directions of motion at the effort and load are related for each of the three classes of lever. By comparing these with the motion they want, they can usually figure out what kind of lever to use.

As an additional challenge, you can suggest that a group add a return spring to its mechanism. It can be made using a rubber band. Another challenge is to explore alternative designs for each of the mechanisms. Also, each mechanism can lead to its own set of research questions: How can the range of motion be increased or decreased? How does the length and placement of a guide change the operation of a mechanism? What are the sources of friction that tend to hang the mechanism up, and how can friction be reduced?