Force & Motion 2-3: MechAnimations

Physical Science Comes Alive: Exploring Things that Go
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Introduction

Overview

MechAnimations are home-made kinetic toys, which depict animals or people with movable body parts. Students begin by making things from pegboard strips and boards. They learn to distinguish between structures and mechanisms, and learn how to make increasingly more complex linkages. These become the basis for understanding and making MechAnimations. They develop a visual language for representing and communicating their designs, learn to control the direction of motion, and investigate how the design of a linkage affects the distance traveled and force required. Finally, they create their final MechAnimations based on the knowledge they have developed about force and distance.

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Background

The best way to prepare for teaching this unit is to try the activities for yourself. A **MechAnimation** is a cardboard construction that uses a mechanism to tell a story, such as a fly swatter hitting a fly, a child eating an ice cream cone or a whale chasing a ship. Students learn about the differences between mechanisms and structures, identify inputs and outputs, make diagrams and models, explore force and motion, and eventually create mechanisms with multiple links, which may eventually become quite complicated!

Pegboard bases and strips are easy to work with, and children can experiment with them quickly. However, they are expensive and hard to decorate, and children cannot take pegboard home with them. Cardboard, on the other hand, is inexpensive, and easy to decorate. In order to create a MechAnimation, a student usually begins by deciding on the story they want it to tell, then they design a model of the mechanism in pegboard, and finally they create and decorate the final cardboard version.

Guide to the Lessons

This unit is subdivided into 12 lessons, each intended for at least one class period. Each lesson is organized into all or most of the following sections:

Overview provides a brief statement of the purpose of the lesson.

Materials lists the supplies needed for the lesson.

Procedure offers a basic lesson plan, including worksheets, focusing questions and prompts for writing entries in the Science Notebooks.

Outcomes states the basic conclusions developed through the lesson.

Assessment suggests methods for determining how well students have attained the outcomes.

Extensions provides additional investigations and design challenges, related to the lesson, but not essential to the sequence. These can be used by students who finish the basic procedure quickly, or for extra sessions, homework or additional assessment.

Troubleshooting offers help to the teacher, pointing out common pitfalls in the activities, and how to address them.

Technical Background provides teachers with relevant science and math content.

Glossary provides definitions of key terms used in the Lesson. This section is for teachers only, and should <u>not</u> be used as vocabulary for students.

Materials

See Figure 1 for photos, and Table 1 for quantities and scheduling

- ✄ Pegboard **bases**, 8" x 12" with $\frac{3}{16}$" diameter holes on ½" centers
- ✄ Pegboard **strips**, 1" x 12" with $\frac{3}{16}$" diameter holes on ½" centers, numbered holes
  1" x 6" with $\frac{3}{16}$" diameter holes on ½" centers

- Three types of **fasteners** for joining pegboard pieces (see Figure 1):
  - Steel flathead rivets, 3/16 " diameter x 5/8 " or 7/8 " long (2 boxes of 100 per classroom);
  - Metal screws, 8-32 x ¾" or 1" long with 8-32 wing nuts (2 boxes of 100 per classroom);
  - Brass paper fasteners, 1 ½ " long (3 boxes of 100 per classroom)
- **Cardstock** for making models and MechAnimations (assorted colors; 65 # or higher, about 1 pack of 250 sheets per class)
- **Corrugated cardboard** for making MechAnimations, 8 ½" x 11" sheets, about 50
- **MechAnimations** (six each of five different types)
- **Cardstock template** of cut-out figures for attaching to pegboard or repairing MechAnimations
- **Masking tape, scissors, Post-Its ™, markers, craft materials, colored pencils**
- **About 25 assorted mechanisms:** These could include scissors, snack food clips, barbecue tongs, clothes pins, can openers, nut crackers, lemon squeezers, egg slicers, garlic presses, tweezers, eyelash curlers, nail clippers, staple removers, glue sticks, etc. See Figure 4 & Table 1 of Lesson 1 for suggestions
- **Science Notebooks**

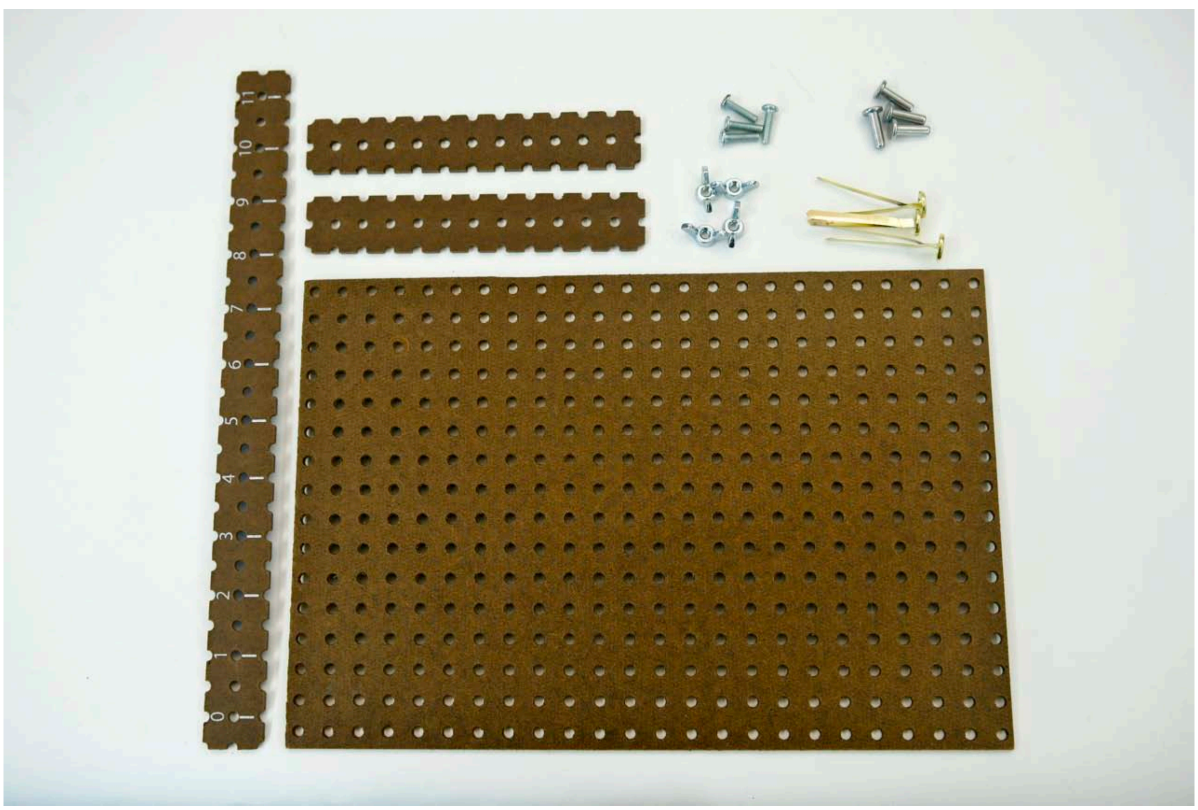


Figure 1: Materials: (top row) short strip, screws, rivets; (middle row) short strip, wing nuts, paper fasteners; (bottom row) long strip, base

Table 1: Materials needed for MechAnimations per class of 30 students

	Lessons												Total
Materials	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
For making mechanisms:													
Pegboard base, 8" x 12"		30	30	30	30	30	30	30	30	30	30		30*
Pegboard strip,. 1" x 12"		100	100	100	100	100	100	100	100	100	100		100*
Steel rivets (box of 100)		1	1	1	1	1	1	1	1	1	1		5*
8-32 Screws with wing nuts (package of 100)		1	1	1	1	1	1	1	1	1	1		5*
Brass paper fasteners 1 ½" (box of 100)		1	1	2		1	1	2	1		2		10
Blank cardstock – ass'td colors (8 ½ x 11")				50				100			100		250
Corrugated cardboard sheet (8 ½ x 11")											50		50
Corrugated cardboard strip (1 x 11")											200		200
Assortment of manufactured mechanisms	50*											50*	
MechAnimations (reusable in multiple classrooms)													
Hammer			1			6				6			6*
Butterfly net						6			6				6*
Windshield wipers							6						6*
Mouse & cheese							6						6*
Frustrated Butterfly net									6				6*
Templates of figures for adding to pegboard or repairing MechAnimations													
Hammer (5/sheet)						6				6			12
Nail (10/sheet)						3				3			6
Butterfly (6/sheet)						5			5				10
Net (2/sheet)									5				5
Mouse (3/sheet)							10						10
Cheese (6/sheet)							5						5
Force probe (20/sheet)									5				5

* reusable items

Lesson 1: Identifying and sorting mechanisms

Overview

Each group is provided with a varied collection of manufactured mechanisms, such as can openers, scissors, nail clippers, etc. First, they make general observations about these devices. Then students look at common characteristics of these devices, and try to determine what properties they share. Finally, the groups sort their mechanisms according to their own secret categories, and challenge other groups to guess their categories.

Materials

- ✄ **About 50 assorted mechanisms.** These could include scissors, snack food clips, barbecue tongs, clothes pins, can openers, nut crackers, lemon squeezers, egg slicers, garlic presses, tweezers, eyelash curlers, nail clippers, staple removers, glue sticks, etc. See Figure 4 & Table 1. About half of these will be supplied; the others can be gathered from students, home & school.
- ✄ **Chart paper and markers**
- ✄ **Post-its ™,** several per group
- ✄ **Science notebooks**

Procedure

1. **Exploration of mechanisms**: Divide students into groups of 4 or 5. Provide each group with a collection of manufactured mechanisms.

   - ✄ *Look at the objects on your table. They are all* ***mechanisms****. As a group, make a list of what you notice.*

   After a few minutes, conduct a whole-class meeting in which you debrief the groups. Ask each group to report only one item from their list, being careful not to repeat any items that have already been reported. Write each observation on chart paper, without commenting on it. Go around the room, soliciting one new item from each group each time, until their lists are exhausted.

2. **Features of a mechanism**: Review the chart-paper list. Using another color marker, highlight the following kinds of entries:

   - ✄ Observations about <u>what you have to do</u> to use them: they work by hand, you have to push or pull, you need to move them to make them work, it takes force, etc.
   - ✄ Observations about <u>what they are used for:</u> each one has a job to do; they have a purpose; they cut, squeeze, mash, poke, grab or break something, etc.
   - ✄ Observations about <u>their structure</u>: they have moving parts, there's a pin or pivot, there's a little circle holding it together, this part doesn't move but the others do, etc.

   Elicit additional observations of each type by asking:

   - ✄ **What do you have to do to make each one work?** Students should notice that each one is operated by hand. You have to push, pull or squeeze something to make it work.

Develop the term **input** for describing the location where you have to do something, to operate it.

- ✁ **Why did they invent these things?** Develop the idea that each one has a special job to do. Some of them cut, some grab, some puncture, etc. Develop the term **output** to describe the outcome of supplying the input.
- ✁ **What parts does each one have?** You've already identified two locations, the input and output. Help students notice that there is also a pin or joint that holds everything together, allowing the other parts to rotate. Develop the term **pivot** for the connector, which permits the other parts to rotate.

Science Notebooks
✁ Draw any mechanism you find interesting. Label its input, its output and its pivot
✁ Explain what it is used for, and what you have to do to operate it.

3. **Sorting game: Guess my rule!** Explain the game to the class:

   Sort your mechanisms according to your own secret categories, which your are not to reveal to anyone outside the group. <u>Each of the mechanisms should belong to only one category</u>. If there are mechanisms that don't fit neatly into any category, suggest a new category called "things that don't fit." Try to make these categories easy to guess – the rule for each category should be pretty obvious. Put each category in a separate pile or area on the table, with a Post-It™ nearby. On the bottom side of the Post-It™, write down the rule for that category, such as "Things that cut."

   Then gather the class around each table to see if others can guess the categories.

4. **Review the categories** that the different groups used. The categories reflect different ways of organizing things. Here are three kinds of categories:

   - ✁ **Science categories** break things down into their basic components. <u>Examples</u>: things that return to their original position when you let them go vs. things that don't; 1st, 2nd & 3rd-class levers (see <u>Extension</u>, below).
   - ✁ **Math categories** look at numbers or geometric patterns. <u>Examples</u>: Number of pivots; inputs and outputs move in the same vs. opposite directions; inputs that make a full circle vs. those that don't.
   - ✁ **Engineering categories** are about what things are used for. <u>Examples</u>: things that cut vs. things that squeeze vs. things that mash, etc.; things you find in the bathroom vs. things you find in the kitchen vs. things you find in school.

Science Notebooks
✁ What categories did you use to sort your mechanisms? List some items from each category.
✁ What other categories could you have used?

Outcomes

In this lesson, students learn that:

- Mechanisms are devices with moving parts.
- You have to operate them by hand to make them work.
- Each one has a job to do.
- Every mechanism has an input and an output.
- You can sort mechanisms according to their basic parts (science), the paths they move in or how many parts they have (math) or the job they do (engineering).

Assessment

- Find a mechanism somewhere in the room, other than the ones you've look at so far. How do you know it is a mechanism? Where is its input, its output and its pivot?
- Find a mechanism in your body. How do you know it is a mechanism? Where is its input, its output and its pivot?

Extension

Classes of levers. Sort your mechanisms according to these four science categories:

- **1st -class levers:** Pivot is between input and output (scissors, pliers)
- **2nd -class levers:** Output is between pivot and input (nutcracker, garlic press)
- **3rd –class levers:** Input is between pivot and output (tweezers, salad tongs)
- **Complex, more than one lever** (nail clippers, vise grips)

Troubleshooting

When students first look at the mechanisms, they are likely to be intrigued by them, and wonder what they are for, but might not notice how they work. Encourage them to hold one part steady, and then look at what moves, what doesn't, how the parts travel, what you have to do to operate it, and what happens as a result.

In the sorting activity (Procedure, Step 4), students may select categories that seem unimportant of superficial, such as color, material or size. Encourage them to look deeper, at how things work, what they are used for, how many parts they have, or how they move.

Technical Background

Any device with moving parts is a **mechanism**. The simplest mechanism consists of a single moving part attached to a **base**, in a way that allows the moving part to rotate. The part that can rotate is called a **lever**. When you use a lever to do a job, there is someplace on the lever that you operate, and another place that actually does the work. As with a video game controller, computer keyboard or calculator keypad, the place that you do something to is called the **input**, and the result happens at another point called the **output**. The lever can rotate, because it is attached to the base by a **pivot.** The input**,** output, and pivot are the three essential parts of a lever. Because it has distinct inputs and outputs, a lever is also an example of a **system**.

In the language of levers, there are special names for the three essential components:

General Term		Language of Levers
Input	⇔	Effort
Output	⇔	Load
Pivot	⇔	Fulcrum

There are three ways to arrange the effort, fulcrum and load. Based on the arrangement, levers come in three categories, which are called 1st- 2nd and 3rd class levers:

1st Class:	Fulcrum …	is in between …	Effort and Load
2nd Class:	Load …	is in between …	Fulcrum and Effort
3rd Class:	Effort …	is in between …	Fulcrum and Load

Diagrams of 1st class levers are shown in Figure 1. A scissors is a 1st-class lever because its input or effort – a handle – is located on the other side of the fulcrum from its output or load – the blade that actually does the cutting.

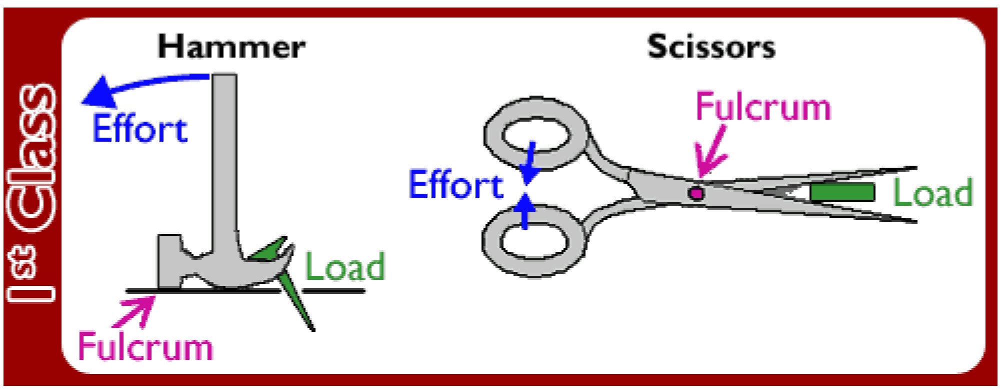


Figure 1: 1st Class levers

Figure 2 shows some 2nd-Class levers. A nutcracker is an example because the fulcrum is at one end, the handles are at the other end, and the load – where the nutcracker crushes the unfortunate nut – is in between.

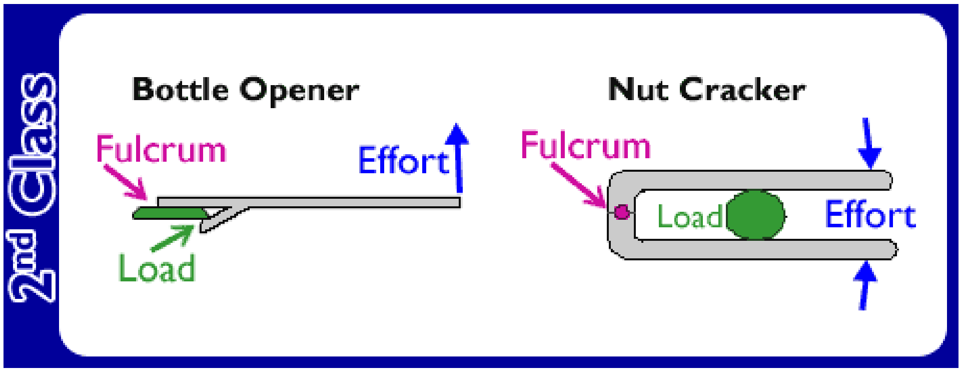


Figure 2: 2nd Class levers

Figure 3 is a diagram of 3rd-Class levers. In a staple remover, the input or effort is where you squeeze, which is in between the fulcrum at one end and the load – where the staple actually gets pulled out – at the other end.

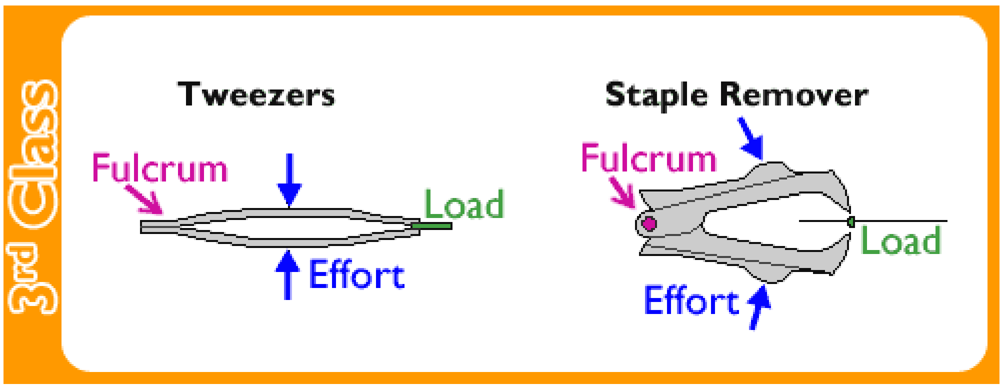


Figure 3: 3rd Class levers

Table 1 and Figure 4 show additional examples of each class, plus diagrams showing the locations of the effort, fulcrum and load in each case.

Scissors Snack food clip Barbecue tongs Leather punch Clothes pin Lemon squeezer hole punchers	Crab cracker Lemon squeezer Garlic press Egg slicer Garlic Press	Garlic separator Tweezers Staple remover Reverse tweezers Tongs

Figure 4: More examples of 1st- 2nd- and 3rd-Class Levers (clockwise from top left)

In a 1st Class lever, the pivot located in between the input and output forces them to move in *opposite* directions: if the input goes down, the output has to go up, just like in a see-saw. Which one moves further? It could be either one – it depends on how far the input and output each is from the pivot.

In a 2nd- or a 3rd- Class lever, both the input and output move in the *same* direction, because both are on the same side of the pivot. A 2nd Class lever has the input further from the pivot, so it will move further than the output. In a 3rd Class lever, the opposite is true. Table 2 summarizes these relationships, including diagrams of all three classes.

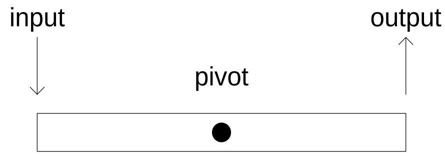
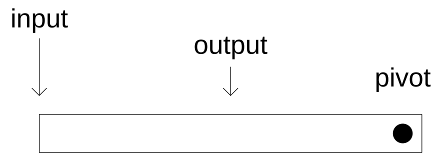
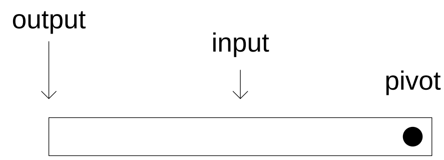
Class	Diagram	Directions of motion	Amounts of input and output motion
1st		Input and output move in **opposite** directions	Variable: depends on distances of input and output from pivot
2nd		Input and output move in **the same** direction	Input moves further than output
3rd			Output moves further than input

Table 2: Directions and amounts of motion for each lever class

Glossary

Effort: Another word for input, used with levers.

Engineering categories: Classification of items based on their uses

First-class lever: A lever in which the fulcrum is in between the input and output.

Fulcrum: A pivot that attaches a lever to another part, usually a base.

Input (of a mechanism): The place on a mechanism that you push or pull in order to make another point move.

Lever: A device with an input (effort) and output (load), which can rotate because it is attached to a base by a pivot (fulcrum).

Load: Another word for output, used with levers.

Math categories: Classification based on numbers or geometric patterns

Mechanism: A set of attached pieces that has at least one moving part, which can move while another part stays still

Output (of a mechanism): The place on a mechanism where you look for something to happen.

Science categories: Classification based on underlying mechanical properties

Second-class lever: A lever in which the output is in between the input and the fulcrum.

Sorting: Arrangement of items according to mutually exclusive categories.

System: A collection of interconnected parts that work together; includes an input and an output.

Third-class lever: A lever in which the input is in between the output and the fulcrum.

Lesson 2: Making mechanisms

Overview

Each student is provided with materials for constructing pegboard mechanisms, and encouraged to make anything they want. Toward the end the period, they share their constructions. The teacher uses the students' work to highlight the distinction between structures and mechanisms.

Materials

- Pegboard **bases** (one per student) and **strips** (three per student)
- Three types of **Fasteners**: rivets, screws + wing nuts, and paper fasteners; box of 100 of each.
- **Science Notebooks**

Procedure

1. **Exploration with materials**: Provide each student with a base, three strips and fasteners of all three types, and encourage students to build whatever they can with these materials. If necessary, demonstrate how to join pegboard pieces using the three types of fastener: rivet, screw plus wing nut and paper fastener. As students are working, you may notice that some students are building without bases. Encourage each of these students to use a base as a platform on which to build.
2. **Whole-class meeting**: Ask each student to show the class what he or she has made. It is likely that some of their constructions will be structures, while others will be mechanisms. Highlight these differences by asking of each one:
   - Does it have any parts that can move separately from others? Or, are all the parts stuck together so they can only move when all of them do?
   - Introduce the words **mechanism** (something that has moving parts) and **structure** (something that can only move as a whole) and write them on chart paper.
3. **Group activity**: Ask each group to sort their constructions according to the two categories, structure and mechanism. What differences do they notice about the things in each category?

<u>Science Notebooks</u>

- Describe what you were trying to make.
- Draw a picture showing what it looks like.
- Is it a mechanism or a structure? How can you tell?

4. **Wrap-up discussion**. Conduct a whole-class meeting to develop what students have learned:
   - How can you tell if something is a mechanism or a structure?
   - How could you change a mechanism into a structure?
   - How could you change a structure into a mechanism?

Outcomes

In the course of this lesson, students should learn to distinguish between mechanisms and structures, and be able to convert one into the other.

- A structure has no moving parts.
- A mechanism does have moving parts.
- To convert a structure into a mechanism, you always have to <u>remove</u> fasteners.
- To turn a mechanism into a structure, you have to <u>add</u> fasteners.

Assessment

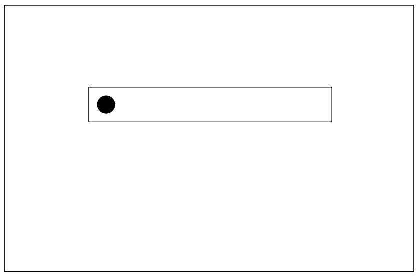
- See Lesson 2 Assessment: <u>Structure or Mechanism</u>? (see next page).
- Using pegboard, build one of the structures (c), d), f) or g)) shown on the Assessment sheet. Ask students: *How would you convert it into a mechanism?*
- Using pegboard, build one of the mechanisms (a), b), e) or h)) shown on the Assessment sheet. Ask students: *How would you convert it into a structure?*

Name: ________________________ Date: _______________

Structure or Mechanism?

Label the Structures “S’ and the Mechanisms “M”

a)



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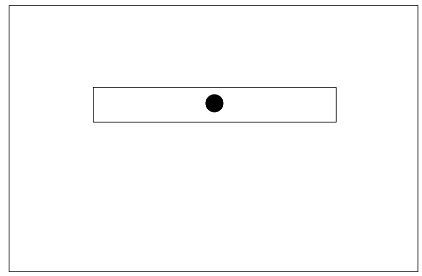

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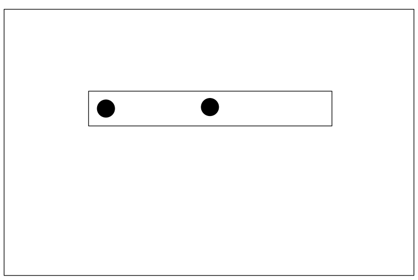

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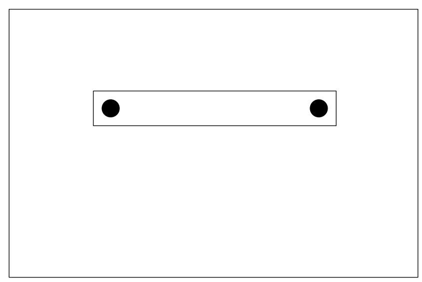
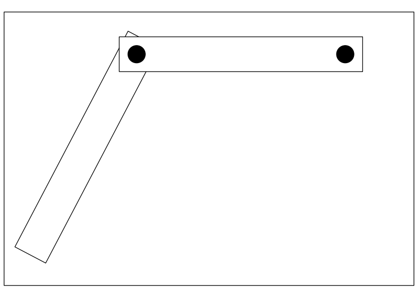
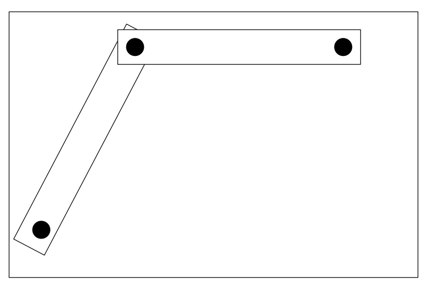


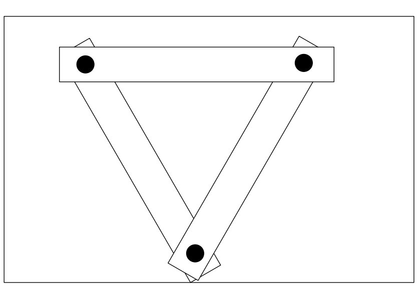
e)



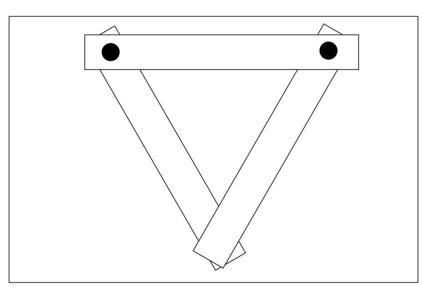
f)



g)



h)



Troubleshooting

Students may have difficulty using the fasteners. Here are some tips:

- ✁ To get the <u>rivets</u> into the holes in the pegboard, it sometimes helps to push them through with the back of a pencil or marker. To get them out, turn the pegboard over and use the same method to push the narrower side back the other way.
- ✁ Students may prefer to use the <u>screws</u>, which are smaller than the holes, and therefore easier to insert. However, they will fall out if not secured by a wing nut. Students may have trouble starting a wing nut on a screw. If this occurs, suggest that they hold the wing nut in place, and turn the screw inside it.
- ✁ The easiest fastener to use is the <u>brass paper fastener</u>. These are secured by folding the legs outward. However, they are not as tight as the rivets, or screws and wing nuts, and the opened legs can interfere with other moving parts.
- ✁ If students become frustrated with any of the three choices of fasteners, suggest that they try one of the other two types.

Technical Background

Any device that has moving parts is a **mechanism**. If something has no moving parts, it is called a **structure**. A structure can move only as a unit – all the parts have to travel together. A desk, chair, box, board or stick is a structure, either because it has only one part, or because none of its parts is supposed to move independently of the other parts. A pair of scissors, stapler, tweezers, door lock or skateboard each has moving parts, so it is a mechanism. The following saying was circulating on-line:

> *There are only two tools you'll ever need: Duct Tape and WD-40™. Here's how you'll know which one to use: if it moves and it shouldn't move, use duct tapel if the opposite is true, use WD-40™.*

In our terminology, Duct Tape converts a mechanism into a structure, while, WD-40™ changes a structure into a mechanism!

Each student has been provided with strips, fasteners and a base. Let's explore what determines whether a construction is a structure or a mechanism. Figure 1 shows four simple construction, each with one strip attached to a base by one or two fasteners, indicated by black circles. Which of these are structures and which are mechanisms?

In the figure, there are four bases, each with one strip. Using the pegboard, make each one to see in which cases the strip can move independently of the base, and is therefore a mechanism.

The strips in a) and b) are <u>mechanisms</u>. Each strip is free to rotate, because each is held by only one fastener. However, the strips in c) and d) cannot move unless the base does too, because the two fasteners hold them securely in the same position on the base. These are <u>structures</u>.

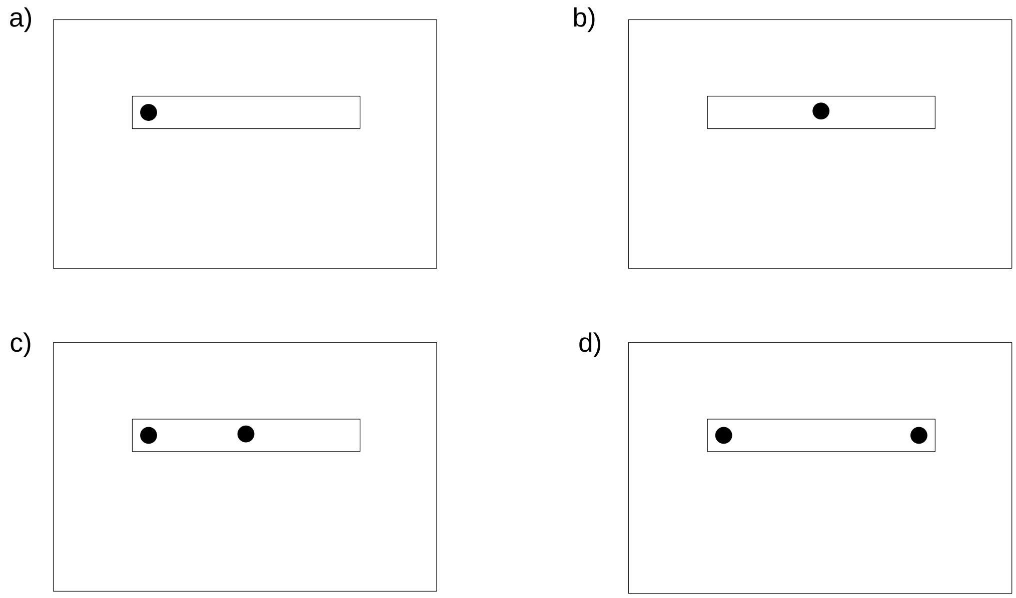


Figure 1: Structures vs. Mechanisms

Why does it matter so much whether there are two fasteners or one? To answer this, recall from geometry that two points determine a line. If the points are the fasteners and the strip is the line, the strip can't move because the fasteners decide what position it has to be in, making it a structure. By contrast, one fastener fixes one point only, but the strip can still rotate around that one point, which creates a mechanism.

More than likely, the students' constructions will be far more complicated than the simple ones in Figure 1. Nevertheless, the same principles apply. Two pivots through the base fix a strip so it forms a structure with the base. One pivot through the base *usually* allows a strip to rotate – but not always.

We've used the words base, strip and fastener to refer to the three components of a construction. These words describe physical parts, but don't tell us anything about the functions of these parts. Now that we've separated the constructions into structures and mechanisms, we'll use new words to begin to distinguish the different ways the basic components can be used.

The **base** is the platform everything else is built on. By itself, the base is always a structure.

Depending on how it is attached, a **strip** might either be free to rotate or not. If it is not free to move, it is simply added to the base as part of the same structure. If it is free to move, it becomes a mechanism. A good name for a strip that can rotate, while attached to a base, is a **lever**. Figures 2 a) and 2 b) are labeled versions of Figures 1 a) and 1 d) showing the terms lever, mechanism and structure.

Just as we did with strips, we'll also need to distinguish between different types of **fasteners**, according to their functions. In Figure 2 a), the fasteners add a strip to a base as part of its structure. These fasteners become parts of the structure too. We'll call a fastener that adds to a structure a **pin**. In Figure 2 b), the fastener is used to attach a lever to a base. This type of fastener we'll call a **pivot**, because it allows something to rotate.

Figure 2: Labeling structures and mechanisms

Figure 3 is a concept map showing the relationships between the terms structure, mechanism, strip, lever, fastener, pin and pivot. We'll add to this map in the next lesson.

Glossary

Base: A stationary platform to which the moving parts are attached.

Fastener: A part that can be used to connect other strips and/or bases. In this curriculum, fasteners can be rivets, screws/wing nuts or brass paper fasteners.

Mechanism: A device with parts that can move, even when the base is fixed.

Pin: A fastener used to add to a structure.

Pivot: A fastener that connects two parts, allowing one of them to rotate.

Strip: A piece that can be attached to a base with a pivot to make a moving part, or with a pin to become part of the structure.

Structure: Something that has no moving parts, which can move only if all the parts move in the same way – by the same amount and in the same direction.

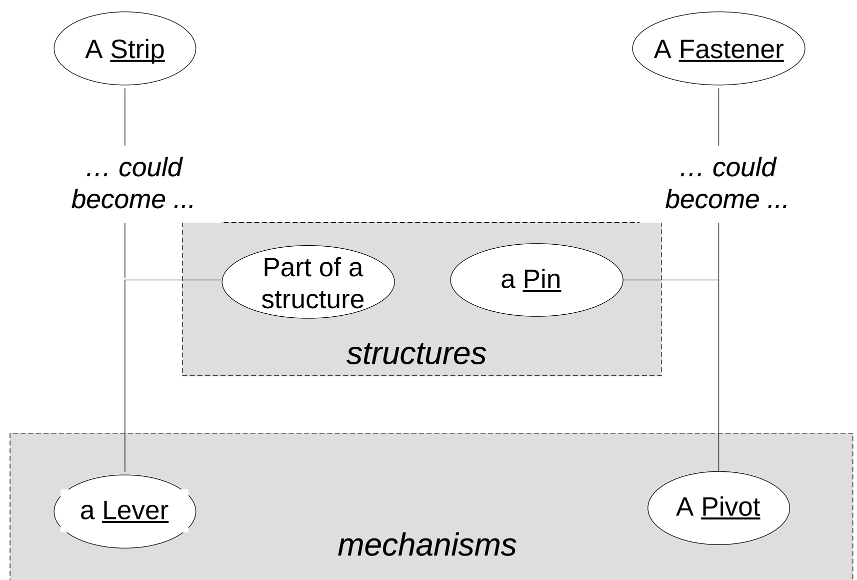


Figure 3: Concept map

Lesson 3: Making one link control another

Overview

Students try to build a pegboard mechanism in which one strip controls another. In order to do so, they will not only need two strips, but also need to invent a new way to use a fastener.

Materials

- **Pegboard bases**, **strips** and **fasteners** (as in Lesson 2), including mechanisms and structures built in Lesson 2.
- **One Hammer MechAnimations**
- **Science notebooks**

Procedure

1. **Demonstrate** a Hammer MechAnimation, without showing what's inside (Figure 1).

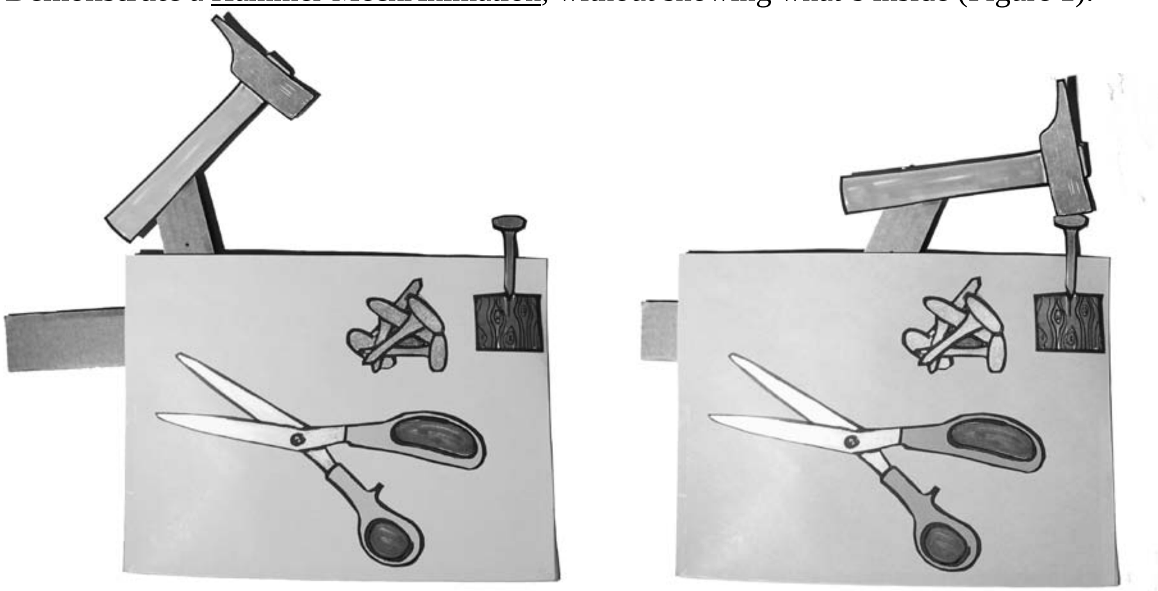


Figure 1: Pushing the input (horizontal strip) to the right makes the hammer hit the nail (output)

   Ask:

   - *What makes the Hammer work?*

2. **Making one strip control another**: Provide each student with a base, three strips and fasteners. These could be the same materials they used in Lesson 2, still assembled or already disassembled. Develop the concept of **control**: you control something when you make it do what you want. Examples could include video game controllers, the controls on a microwave or other appliance, parents and children, teachers and classrooms, principals and schools, etc. (at times!) Set the design challenge:

   - *Make a mechanism using at least two strips. One of the strips should control the other.*

3. **Whole-class discussion**: Students share their constructions. Highlight those in which one strip does actually control another, vs. those where it doesn't happen. As appropriate, revisit

the distinction between structures and mechanisms (see Lesson 2). As questions and issues come up, record them on chart paper. Examples of issues might include:

- Some strips can't move.
- I can't make one control another.
- I can make one move the other by pushing, but not by pulling.
- The end of the lever does not move in the right direction.
- It doesn't move far enough.
- I would like my mechanism to have more than one output, like the MechAnimation.
- The strips can move around too much.

These should be kept for future reference, and used as a basis for further exploration and design. It is far more important that children continue to think about these problems than it is for them to have "an answer."

Before collecting the mechanisms, make sure each student writes his or her name on the mechanism, using a marker and masking tape. They will need these for future lessons.

Science Notebooks

- What were you trying to do?
- What did you make?
- What problems did you have?

Outcomes

This lesson develops the idea of control: one strip can control another only if it can make the second one move in either direction. Students should discover that in order to make one strip control another, they will need to use a fastener that connects one strip to another, but not to the base.

Assessment

- Make and demonstrate a pegboard construction like in Figure 2. Does Y control X? Why or why not?
- Make and demonstrate a pegboard construction like in Figure 3. Does Y control X? Why or why not?
- How could these mechanisms be changed in order to make one strip control another?

Troubleshooting

An obvious way to attempt the design challenge would be simply to push the first strip with a second, as shown in Figure 2: a) shows the original strip X. In b), another strip Y is lined up with the bottom of X, and in c), used to push the bottom of X to the right. However, this method does not satisfy the goal of controlling X, as you can see in 2 d). When Y is pulled back to the left, X does not follow it.

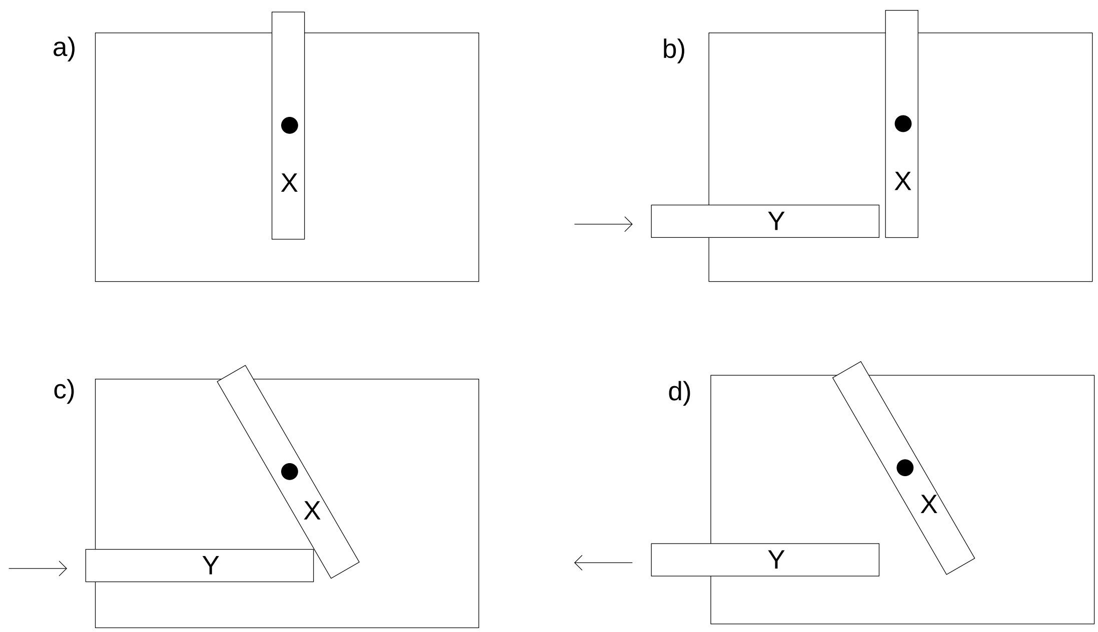


Figure 2: Y does not control X; it can push it in one direction, but not pull it back

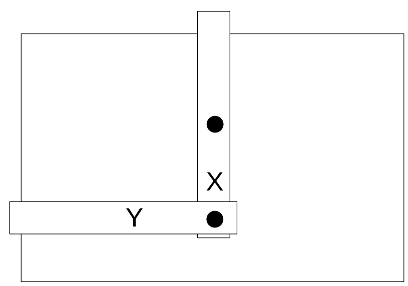


Figure 3: Second (failed) attempt to make Y control X

In order for Y to control X, it needs to be attached to it somehow. Another idea would be to put a fastener through X, Y and the base, as shown in Figure 3.

This second method is even worse than the first, because now X can't move at all! Why not? As the Technical Background for Lesson 2 shows, putting two fasteners through a strip and the base makes the strip and the base into a **structure**. That is exactly what has now happened to strip X.

The solution is to use a fastener that connects X and Y to *each other*, but *not to the base.* The easiest way to accomplish this is to first put a fastener between strips X and Y, as in Figure 4 a). Then attach X to the base, as in Figure 4 b).

Up to now, all of the fasteners have attached strips to bases. Once a fastener goes through the base, it is not free to move, but it may allow a lever to move. We'll call a fastener that can't move itself, but allows a strip to rotate, a **fixed pivot**. A fastener that can move with a strip, because it is not attached to the base, is called a **floating pivot**. Any strip that can move is a **link**. In Figure 4, the floating pivot is shown by an open circle, while the floating pivot is shown by a solid circle.

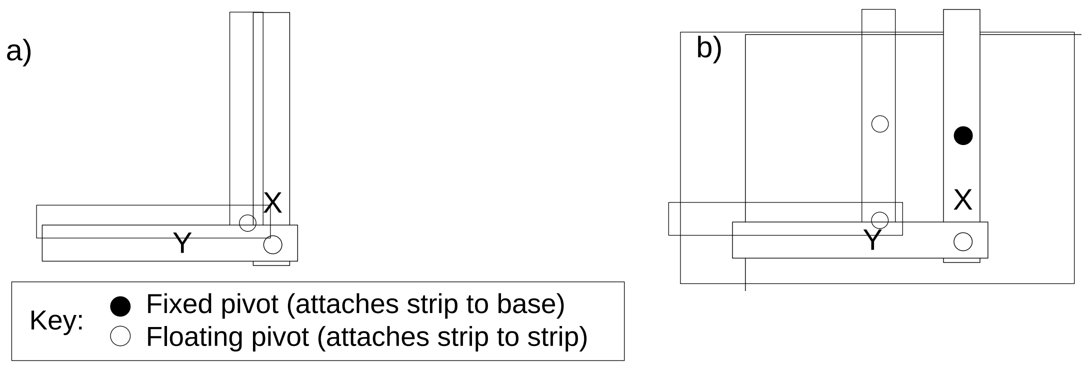


Figure 4: Assembling a mechanism in which one strip controls another

The result is a mechanism that meets the challenge, as shown in Figure 5. Pulling Y to the left rotates X clockwise (Figure 5 a)), while pushing it to the right rotates X counterclockwise. (Figure 5 b))

Figure 5: Strip Y now controls strip X

One remaining issue is how to restrict link Y so it moves only back-and-forth, as shown in Figure 5; in other words, how to prevent it from rotating up and down, as shown in Figure 6 a). Figure 6 b) shows a simple solution: insert a pair of rivets into the base, above and below link Y, that keep it moving horizontally. These two rivets serve as a **guide** for restricting the motion of Y to a horizontal line.

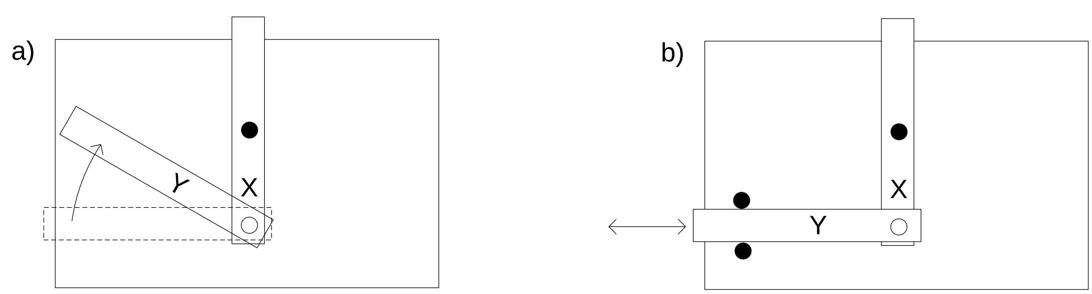


Figure 6: To keep link Y from rotating up and down, as in a), use a pair of rivets to make a **guide**, as in b)

Technical Background

We'll use **link** as the generic term for any strip (or other shape) attached to a base that becomes a moving part. Two categories of link are **lever,** which was already defined in Lesson 1, and **input link,** which is a link used to control a lever. We'll continue to use **pivot** as the generic term for a part that attaches strips and/or bases, allowing at least one strip to rotate. However, we now have two types of pivot: the **fixed pivot** (or fulcrum), which attaches a link to a base; and a **floating pivot**, which attaches two links, but neither to the base.

Students may have difficulty keeping track of bases, links, fixed and floating pivots. Here are two examples you can use from your own body. Lift one leg and move your thigh around; or move your arm, without moving your upper body. Where is the base, where are the links and where are the pivots? Which pivots are fixed and which ones are floating?

In both cases, your torso is the base. The links are the thigh and lower leg; or upper arm and lower arm. When you lift one leg, your hip and knee are both pivots, but your hip is fixed because it is attached directly to your torso, while your knee is a floating pivot. When you move your arm, the shoulder is a fixed pivot, attached to the torso, while the elbow is a floating pivot, because it can move with your arm.

The concept of **control** is fundamental in science and engineering. It involves making something happen from a distance, such as using a wall switch to turn on a light overhead. Control implies a high degree of power and predictability over whatever is controlled. The loose strip Y in Figure 2 can push the bottom of the lever to the right, but *does not* provide control when it is pulled to the left. In the second case, the controlled lever X does not move. It is like a light switch than can turn a light on, but not off! In Figure 5, strip Y is attached to the lever, and therefore *does control* it, because it is able to determine its motion in either direction. A control should be able to determine the state of the system, like a switch that can turn a light either on or off.

Related to control are the concepts of system, input and output. A **system** is a collection of interconnected parts, which function together as a whole. The point at which you operate a system is called the **input**, and the point where it does the intended job is the **output**. The input is the point where you operate the lever, such as a handle of a pair of scissors; and the output is the point where it does useful work, such as the blade of a pair of scissors. A control is another kind of input, one step removed from the lever itself.

Illustrated Glossary

Control: Part of a system that works from a distance to make something else do what it's "told" to; a type of input.

Fixed pivot: A pivot that attaches a link to the base; also called a **fulcrum**.

Floating pivot: A pivot that attaches one link to another, but neither to the base, such as a pivot connecting an input link to a lever.

Guide: A part of the base structure added to restrict the motion of an input link or an output link.

Input link: A link used to control a lever.

Input: The part of a system that a person operates.

Lever: A link that is attached to the base by a fixed pivot.

Link: A strip (or other shape) that serves as a moving part.

Output: The part of a system that does the job the system is intended for.

Pivot: A fastener used to attach two parts together, allowing at least one to rotate.

System: A collection of interconnected parts that work together and includes an input and an output.

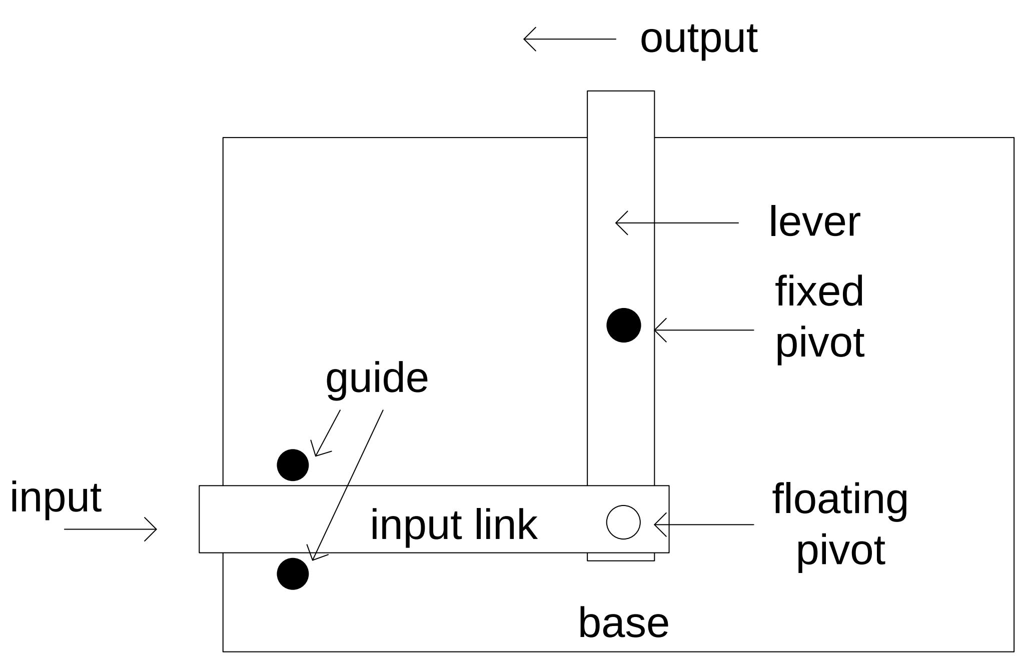


Figure 7: A mechanism in which one link controls another, showing names of parts

Because we've introduced some new terms, we need to revise the concept map in Figure 3 of Lesson 1. Figure 8 shows how a **strip**, as part of a mechanism, becomes a **link,** which could be an **input lever** or a **lever**, depending on how it's used**.**

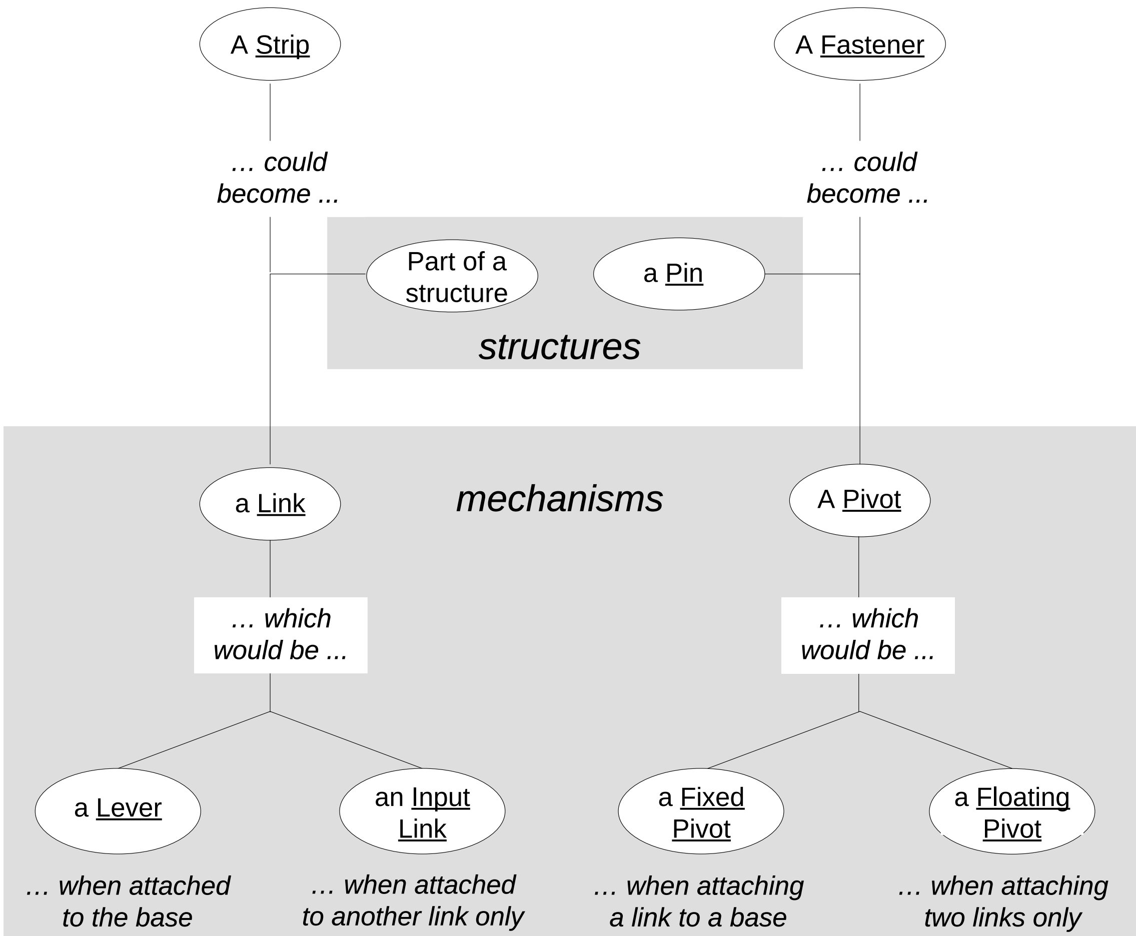


Figure 8: Concept map summarizing different types of strips, fasteners, links and pivots

Lesson 4: Representing Mechanisms

Overview

Each student is challenged to represent his or her mechanism by a diagram, which someone else could use to make a copy of the original mechanism. To construct their diagrams, the class will have to identify the various components of a mechanism. For the diagrams to be readable by everyone, they will use a set of symbols that everyone agrees on.

Materials

- **Pegboard mechanisms** students have made in Lesson 3
- **Mechanism Diagram Template** (at end of Procedure), one per student
- **Science Notebooks**
- **Colored pencils**

Procedure

1. **Brainstorming about drawings, diagrams and maps**: In a whole-class meeting, ask students:

   - *Can you think of a situation where you used a diagram to tell you how to make or do something?*

   Examples might include using a diagram for assembling furniture or construction sets such as Lego™ or K'NEX ™, finding something on a map or floor plan, following a plan for unpacking something from a box, using a graphic recipe from a package. In case students don't think of these, it would be helpful to share samples that you might have handy: floor plans from museums, zoo maps, Lego™ or Ikea™ instructions, recipes, etc. Write each example on chart paper. Then engage students in a brief discussion about the question:

   - *How does it help to have a diagram?*

   Develop the idea that a map or diagram tells you how to make something (or get somewhere) or without already having it in front of you.

2. **Keeping track of your mechanism:** Introduce problem of recording the mechanisms students have made. Suppose you wanted to take your mechanism apart, in order to reuse the pieces to make a new one:

   - *How would you be able to remember what you made earlier?*
   - *How would you be able to explain what you had made to a parent or a friend?*

   Conduct a discussion about these issues. Students will probably suggest making drawings.

3. **First drawings of mechanisms:** Provide paper and markers, and encourage students to record their constructions in any way they choose. Provide some drawings of your own as examples. Some of them should deliberately be hard to read. Engage students in thinking about what makes a drawing easy or hard to figure out.

   Here are some specific issues you might raise:

✂ *How much of your mechanism do you need to show, in order to explain how to build it?*

✂ *What* ***symbols*** *would be handy to show things that we use often?*

Develop ideas about how symbols are used to indicate "Boy's bathroom" or "Girl's bathroom"; "Stop" or "Go"; "McDonald's"; "In case of fire, use the stairs"; etc. What kinds of things would they like to have symbols for, in order to represent their constructions?

Help them think about which kinds of things are really different, and therefore need to have different symbols. For example, if they have suggested only one symbol for "fastener," ask:

✂ *Do all fasteners work the same way?*

(See Lesson 3). If not, how will someone reading the drawing be able to tell what kind of fastener to use?

Let them come up with the idea of having different symbols for different kinds of fasteners, such as fixed and floating pivots. Then suggest that they use the symbols in Figure 1 for fixed and floating pivots:

● Fixed pivot (attaches strip to base)
○ Floating pivot (attaches strip to strip)

Figure 1: Standard symbols for fixed and floating pivots

Science Notebooks

✂ What information should a diagram have, in order for somebody else to use it?

✂ What would make your diagram hard for somebody else to read?

4. **Using the template and colored pencils to make better diagrams**: Provide each student with a Mechanism Diagram Template (at end of Procedure). Each small square on the diagram corresponds to a hole on the pegboard. If you place a pegboard base on top of the template, you can move it so the letters appear just to the left of the last column of holes on the left side, and the numbers are just below the bottom row of holes. Then every hole in the pegboard (except at the very top and extreme right) will have its own specific location on the template. See Figure 2.

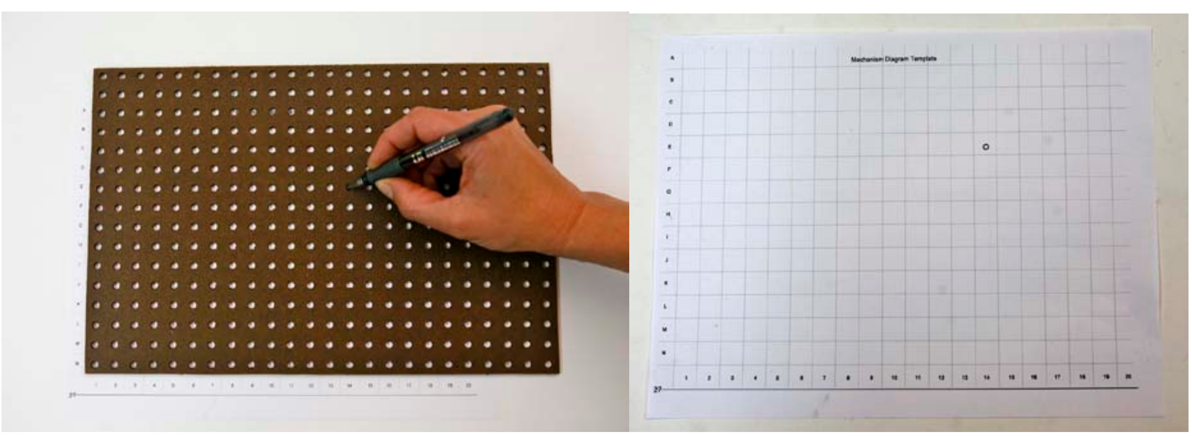


Figure 2: Using the Mechanism Diagram Template

Explain how they can use the template to mark the hole locations they used, without having to draw in every hole. (Only a few of the holes on the far right side CANNOT be represented on the template, because it is not quite as wide as the base.)

Ask each student to make a diagram of his or her mechanism using the template, so that someone else could build it just by looking at the diagram. Allow enough time so that everyone can complete their diagrams. Also, provide colored pencils so students can use them to highlight particular features, or keep track of changes they have made.

As they are working, collect a list of issues that come up. These can either be questions that students ask, or issues that you notice as you are circulating. Post this list for the whole-class discussion that follows. Ask students to write their names on their diagrams, and then post them on a wall or bulletin board where everyone can see them.

5. **Gallery Walk**: Once students have made their own diagrams, post them around the room, and conduct a discussion about what you can learn from each one. Next, students will look at all the posted diagrams, and make some general observations about them. Find positive features of each one, and use the discussion to develop ideas about what makes a good drawing. You might also challenge the class to find differences between the drawings and the original mechanisms. Emphasize that nobody should feel bad if it doesn't work out – the purpose is to learn how to make and follow a drawing, not to make an exact copy.

6. Whole-class discussion: Ask students for their observations on each of the focusing questions from the Gallery Walk, as well as any other observations they might have. After the lesson, remove the diagrams from the wall, and save them for the next lesson.

Outcomes

Each student should be able to explain why a diagram is useful, and the kinds of information it should show. They should each be able to construct an accurate diagram of a pegboard mechanism, using different symbols for fixed and floating pivots, and be able to explain why different symbols are needed.

Assessment

Most important, Students' diagrams should be accurate representations of their mechanisms. Students should also be able to answer the following questions.

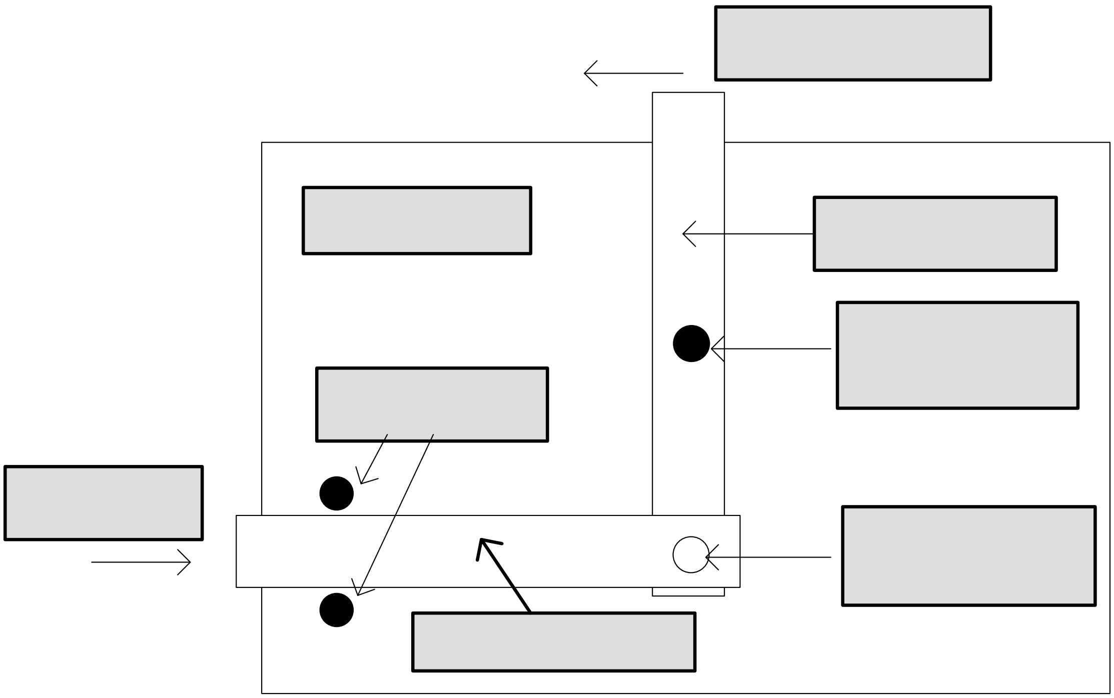
- What is a diagram?
- Why is a diagram useful
- What should a diagram show?
- What would happen if you used the same symbol for all pivots?
- How could you tell if your diagram was accurate?

The Assessment sheet Labeling the Parts (see next page) can be used to review the names and symbols used in the diagrams. Figure 7 of Lesson 3 is an Answer Guide.

Name: ____________________ Date: ________________

Labeling the Parts

Fill in the name of each item on the diagram:



<u>Terms to choose from</u>:

Fixed pivot

Floating pivot

Input

Output

Base

Lever

Input link

Guide

Mechanism Diagram Template

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A																				
B																				
C																				
D																				
E																				
F																				
G																				
H																				
I																				
J																				
K																				
L																				
M																				
N																				

Troubleshooting

The challenge of creating a diagram to represent a mechanism will be difficult for some students. Some of the issues are identified in Procedure, Part 4. The following guide is an attempt to scaffold each of the four major steps:

1. **Identifying the parts of a mechanism**. The first problem is to identify all the parts of a mechanism that need to be represented on a diagram. These include the **base**, **links**, **fixed pivots**, **floating pivots** and possibly **guides**.
2. **Inventing a symbol for each part**. Each of the parts needs to have its own symbol, because otherwise they will be confused with each other. A common oversight is to use the same symbol for fixed and floating pivots, making it difficult to use the diagram to construct a mechanism. If there is only one symbol for both kinds of pivot, which kind of pivot should I use?
3. **Showing what the symbols mean**: Anyone who reads the diagram will need to know what each symbol means. On a map or floor plan, this problem is solved by including a **key**, which is a table that translates between symbols and words. Figure 3 shows the same diagram as in Figure 7 of Lesson 2, except that a key is added to replace the labels.

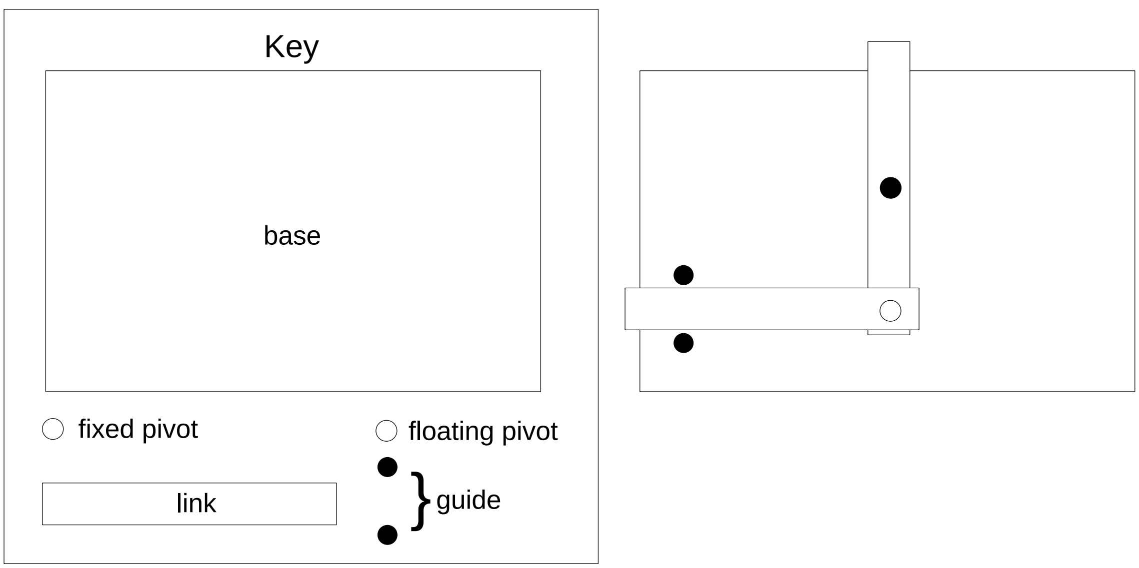


Figure 3: Diagram of a mechanism, using a key to explain the symbols

4. **Eliminating unnecessary details**: From the modeling activity of Lesson 4, students should recognize the importance of finding the hole locations. The obvious way to do so is to show *every* hole, and indicate somehow which ones are actually used. However, this solution clutters up the diagram, making it difficult to read. A much more legible way to show *only* the hole locations that are actually used. An efficient way to do this is to use a **coordinate system**. Most road maps are divided into squares, each of which is labeled by its row and column. The rows are usually identified by letters, starting with “A” at the top, and continuing down the page. The columns use numbers, beginning with #1 at the left end, and counting from left to right. The Mechanism Diagram Template uses the same scheme.

Figure 4 shows how to identify a particular hole in the pegboard base. Place the base over template, so the holes on the left side of the pegboard base are just to the right of the letters, and the holes on the bottom of the base are just above the numbers. Then use a pencil or pen to mark the template through the hole you want to identify. In the example shown, the mark is in row G and column 13. Its coordinate location would therefore be called "G13."

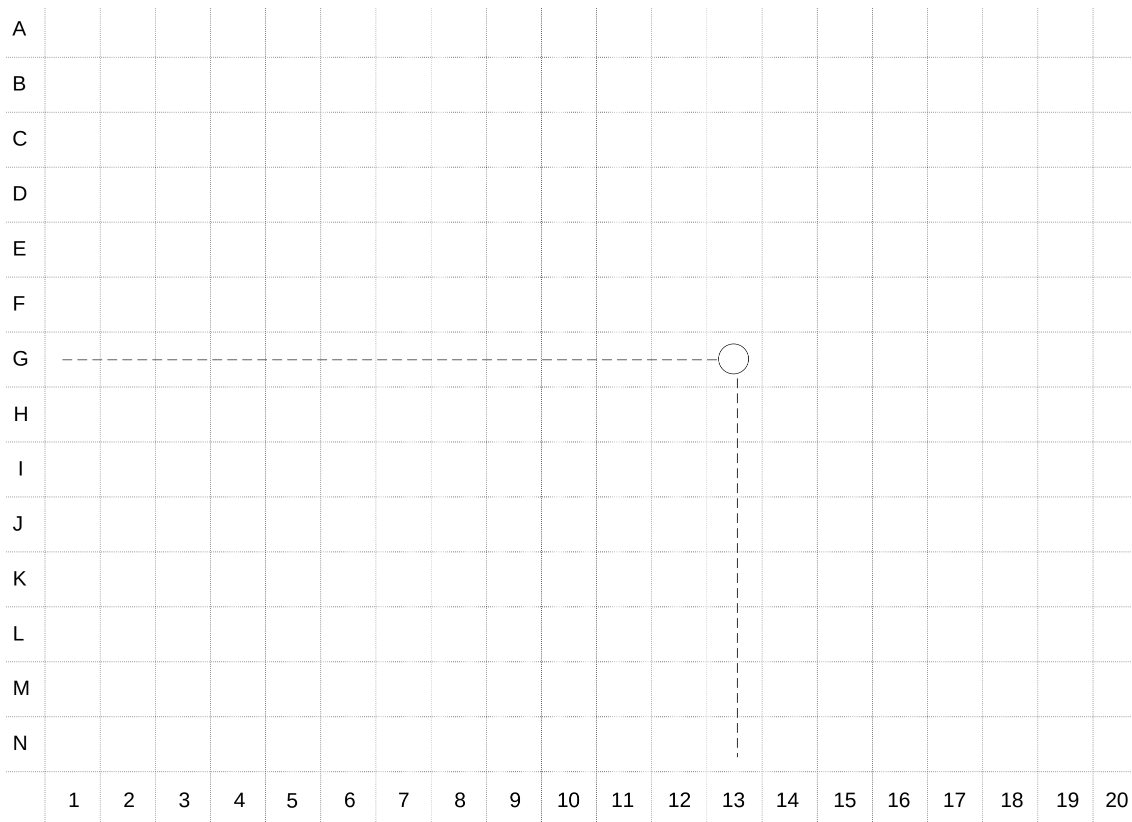


Figure 4: Coordinate system used to identify hole locations

When reproducing the mechanism from the diagram, you can use the same system in reverse. Place another pegboard base over the template in the same way as before, and mark the hole on the base that corresponds to the hole marked on the diagram.

Technical Background

Some students are likely to say, "I can't draw." This lesson is not really about **drawing**, which usually means creating a pictorial likeness of a person or thing. The challenge is instead to construct a **diagram**, which has a different purpose from a drawing, although the two seem similar. A diagram is like a model, in that it captures the most important features of the real thing, while leaving out details that would get in the way of understanding. The difference is that a diagram is two dimensional, while a model is 3D, and therefore closer to the real thing. On the other hand, a diagram is often easier to make than a model, because it only requires pencil and paper.

A **symbol** is a gesture, sound, mark or image that represents an idea, action or object. Examples are words, arithmetic symbols, logos, pictures used on street signs, etc. All communication takes place by means of symbols. Some symbols are so familiar or obvious that nobody needs to explain them, except perhaps to young children or visitors from another society. Other symbols are not so clear, so they need to be translated into a familiar language. A translation table used on a map or diagram is called a **key**. It shows what each symbol means in ordinary language. Figure 3, above, shows an example of a key.

A **coordinate system** is a scheme for assigning numbers and/or letters to locations. The idea is to assign a symbol called a **coordinate** to each direction in 2D or 3D space, and then identify any location by its row and column coordinates. In two dimensions, two coordinates will identify any square in a grid. The most commonly used coordinate system, Cartesian coordinates (named after Descartes) consists of two number lines, one at right angles to the other. Cartesian coordinates are used to make graphs. However, coordinates can be letters or other symbols, as well as numbers. Figure 4 shows a coordinate system that uses letters for the rows and numbers for the columns, similar to the coordinates used on road maps. Other kinds of coordinate systems are used in chess and checkers, as well as street and house numbering (e.g., 671 9th St.). Latitude and longitude are geographical coordinates adapted to a sphere, usually the earth.

Glossary

Coordinate: A number or letter used to represent a location, as part of a coordinate system.

Coordinate system: A system for identifying locations in 2D or 3D, by combining symbols showing locations along each dimension; each symbol is called a coordinate.

Diagram: A 2D representation that shows only the most important features of something.

Drawing: A 2D representation that shows as much information about something `as possible

Key: A table used to show what each symbol in a map or diagram means.

Symbol: A gesture, sound, mark or image that represents an idea, action or object.

Lesson 5: Directions of Motion

Overview

Students compare the directions of motion between the input and output, and learn to make mechanisms of two types using pegboard.

Materials

- ✁ **6 Hammer MechAnimations and 6 Butterfly MechAnimations**
- ✁ **Pegboard mechanisms** students have already made in Lesson 3
- ✁ **Tape** and **Templates for making hammer-, nail-, butterfly- and net-cutouts** to attach to pegboard.
- ✁ **Science Notebooks**

Procedure

1. **Demonstration of the Butterfly and the Hammer**: Demonstrate the Butterfly and Hammer MechAnimations several times each (see Figure 1). Ask students to identify the input of each MechAnimation, and then label each input with a colored Post-IT™ or marker. Then ask them to describe the story each one is telling, when you operate the input.

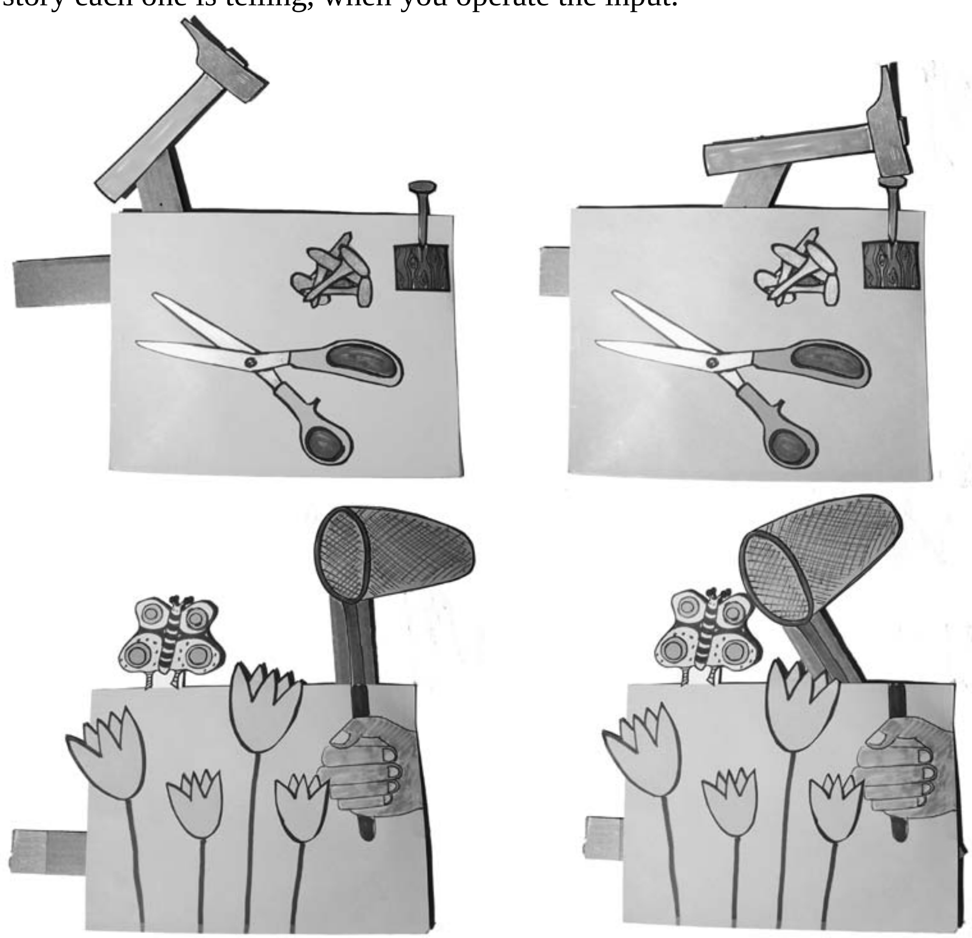


Figure 1: Hammer and Butterfly MechAnimations

Provide each group with a sample of each MechAnimation, and each student with a copy of the Butterfly & Hammer Worksheet. Ask students to identify the input and output of each one, and fill out item #1 of the Worksheet. Review "left" and "right." Then ask students to look very carefully as you operate the input of the Butterfly. Which way does the output go when you move the input to the right? Which way does it go when you move it to the left? Ask students to fill out Item #2 of the Worksheet. Repeat using the Hammer and Item #3 of the Worksheet

2. **Sorting:** Distribute the pegboard mechanisms students have already made in Lesson 3, or allow time for making new ones. Each mechanism should have two links, one that controls another. Ask each group to set aside some space for sorting their group's mechanisms. They should label three areas in this space:

   a) Butterfly Net b) Hammer c) not sure

   Using their worksheets as guides for each type, ask students to operate each mechanism. Then they should make a decision about each one:

   ✁ *Does it work like a) the Butterfly Net or like b) the Hammer?*

   Based on their decision, they are to place each mechanism in area a) or b) in the space you have assigned, area c) for ones they can't decide about.

3. **Designing and Making Mechanisms**. Focus on the mechanisms in areas a) and b) (If time permits, you might help the class decide about some of the ones in area c).) Then provide cutout figures of the hammer & nail, and butterfly & net, for students to attach to pegboard. Pose the following challenge:

   ✁ *You have found mechanisms you made that work either like the Butterfly or like the Hammer MechAnimation. Now make one that works the other way from the one you made before. So, if you made a butterfly before, make a hammer now. If you already made a hammer, now it's your turn to make a butterfly.*

Science Notebooks

✁ Make a diagram showing the butterfly-type mechanism, and another showing the hammer-type mechanism, using the symbols from Lesson 5.

✁ From your diagrams, how are the two types of mechanisms different?

✁ Explain in words and diagrams how to turn a butterfly-type mechanism into a hammer-type mechanism, or *vice versa*.

4. **Whole-class discussion.** Ask students to discuss what they did, what they learned and the problems they encountered. Then ask them to look at the mechanisms that work like butterflies, and compare them with those that work like hammers. Record their observations and conclusions on chart paper.

Outcomes

Students should discover that:

- In a Butterfly-type MechAnimation, the input and output move in opposite directions.
- In a Hammer-type MechAnimation, the input and output move in the same direction.
- To make the input and output move in opposite directions (Butterfly), you have to put the fixed pivot between the floating pivot and the output.
- To make the input and output move in the same direction (Hammer), you have to put the fixed pivot on the opposite side from both the floating pivot and the output.

Assessment

Show students both types of mechanism.

- How are they different?
- In each one, do the input and output travel in the same or opposite directions?
- How could you turn a Butterfly-type mechanism into a Hammer-type?
- How could you turn a Hammer-type mechanism into a Butterfly-type?

Extension

Challenge students to make a mechanism whose output goes up when the input goes to the right – as in Figure 2.

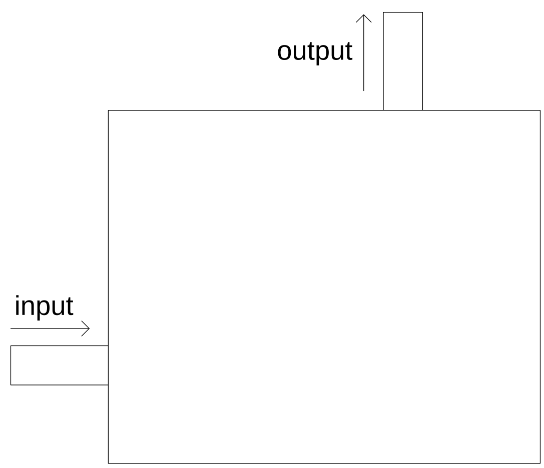
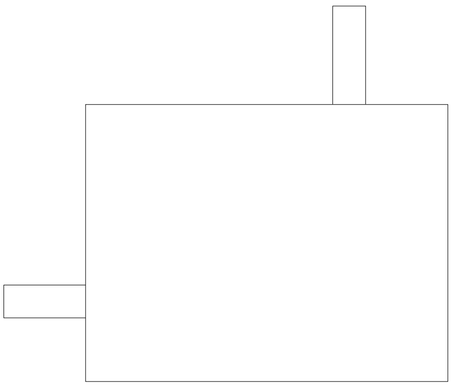


Figure 2: Output goes at right angle to input

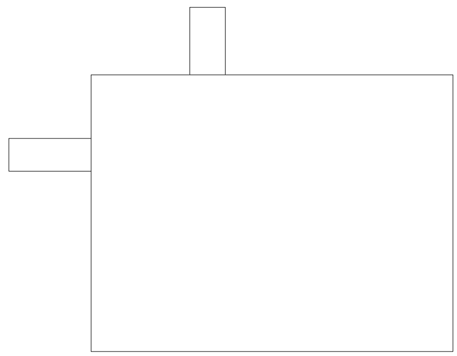
Name: ____________________ Date: _______________

Butterfly & Hammer Worksheet

1. **Inputs and Outputs:** Write the word INPUT where you think the input is. Write the word OUTPUT where you think the output is.

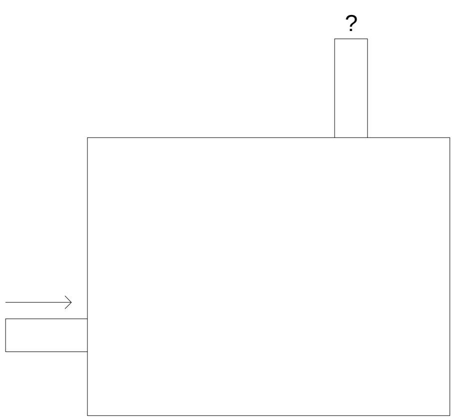


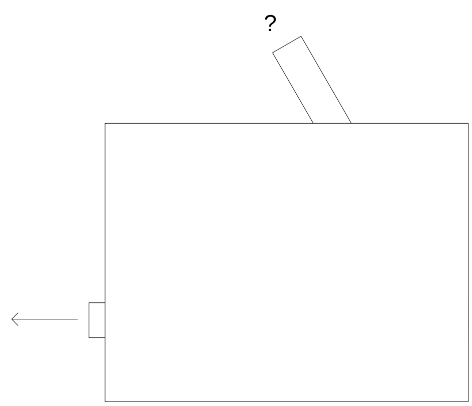
a) Butterfly



b) Hammer

2. **Butterfly Net:** Use an arrow to show which way the output moves for each way the input moves:

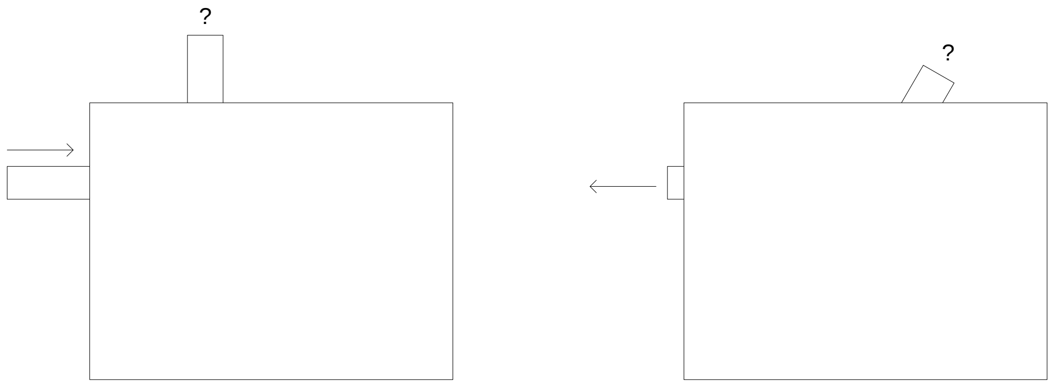




Do the Butterfly input and output move in the SAME or OPPOSITE directions? ________________

Butterfly & Hammer Worksheet, Continued

3. **Hammer:** Use an arrow to show which way the output moves for each way the input moves:



Do the Butterfly input and output move in the SAME or OPPOSITE directions? _______________

4. **Sorting**: How could you tell if something works like a Butterfly or like a Hammer?

Butterfly:

____

____

Hammer:

____

____

Troubleshooting

Students may feel that the pictures in the worksheet don't look much like the MechAnimations. Remind them about how they drew diagrams in Lessons 4 and 5 to capture the most important features of a mechanism, without including details that are not important. The pictures on the Worksheet are all diagrams. Details such as the hammer, nail, butterfly and net are not shown, because they don't tell anything about how the mechanism actually works.

The worksheet requires careful observation, and may be difficult for some students. Their conclusions should be that the input and output move in opposite directions in the Butterfly and in the same direction in the Hammer.

Here's why. In the Butterfly, the fixed pivot is in between the input link and the output, which causes them to turn in opposite directions. In the Hammer, the fixed pivot is opposite both the input link and the output, so they move in the same direction. (See Technical Background for further information about pivot locations and lever classes). Figure 3 shows the two constructions; Figure 4 is a diagram of the motion of the Butterfly Net as the input moves right and left. Figure 5 is a similar diagram for the Hammer.

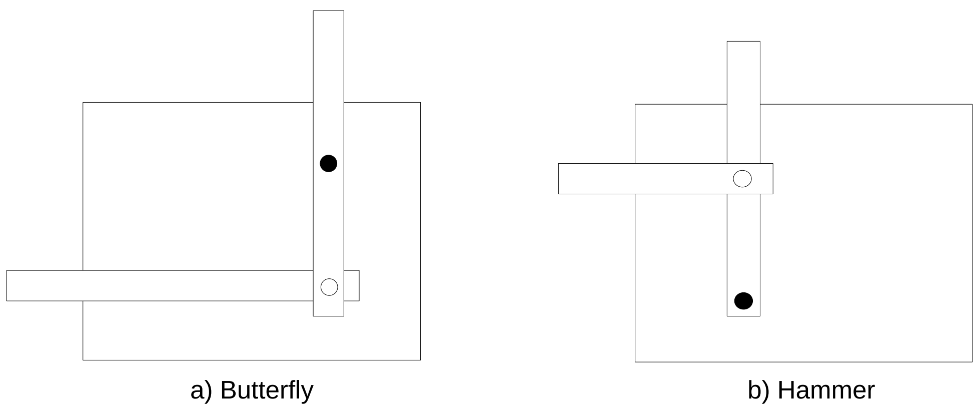


Figure 3: The mechanisms inside the Butterfly and the Hammer

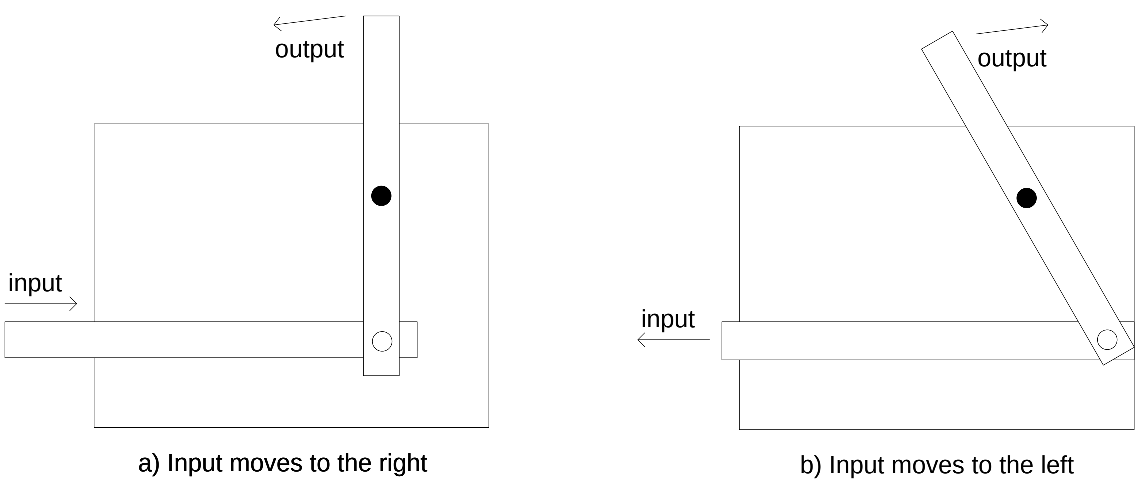


Figure 4: Motion of the Butterfly Net output as the input moves a) right and b) left

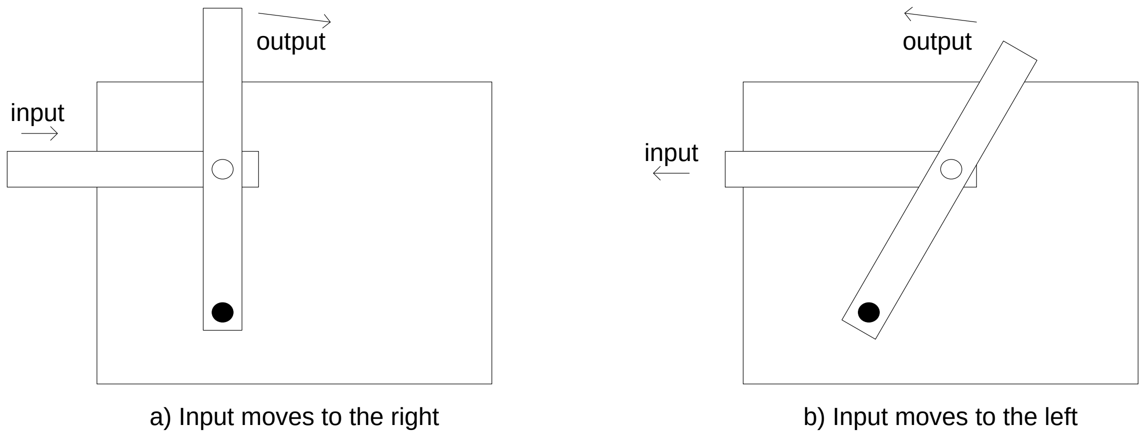


Figure 5: Motion of the <u>Hammer</u> output as the input moves a) right and b) left

During the sorting activity, focus on mechanisms that have one lever and one input link. These will have to be of one type or the other, depending on the location of the fixed pivot in relation to the input link and output. It is possible that most or all of the student-made mechanisms will be of the same type, most likely <u>Butterfly</u>-type. If so, assemble a <u>Hammer</u>-type pegboard mechanism for each group that doesn't already have one, so they will be able to compare the two types. This will help them especially during the design and construction activity in Step 3. Help students check each mechanism after they have made it, to make sure it works they way they want: do the input and output travel in the same or opposite directions?

The <u>Extension</u> activity is not easy. Two solutions are shown in Figure 6. The solution in a) can be made using pegboard. Note that there are <u>three</u> links, (x, y and z) joining two floating pivots and one fixed pivot. Link z is shown with a dashed line, because it must be stacked above, below or in between the other two pairs. Together, these three form a triangle, which by itself is a structure. In fact, these three links can be replaced by a triangle, made for example of cardstock, as shown in Figure 6 b).

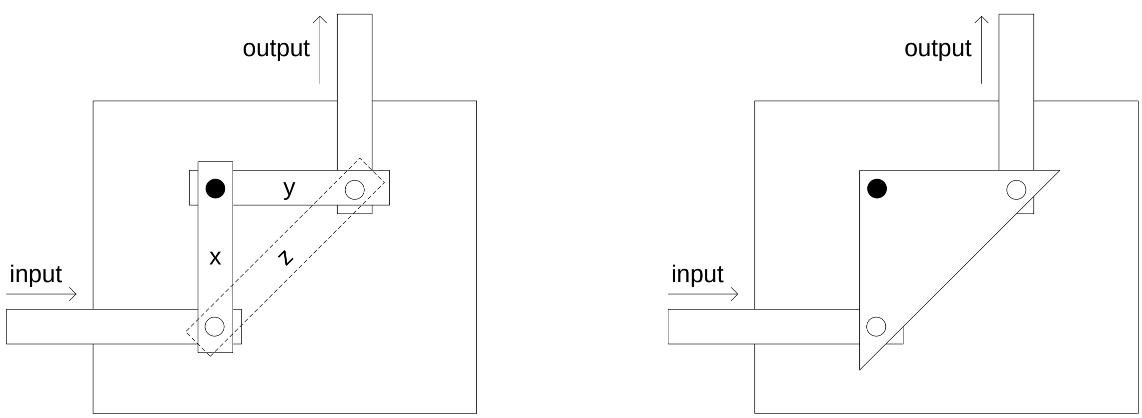


Figure 6: How to make the input and output move at right angles to each other

The triangle is called a <u>bent first-class lever</u>. It works because the fixed pivot of the bent lever is off center from both the floating pivots. Figure 7 a) illustrates how the triangle forces the output to go up when the input goes to the right, and *vice versa* in Figure 7 b).

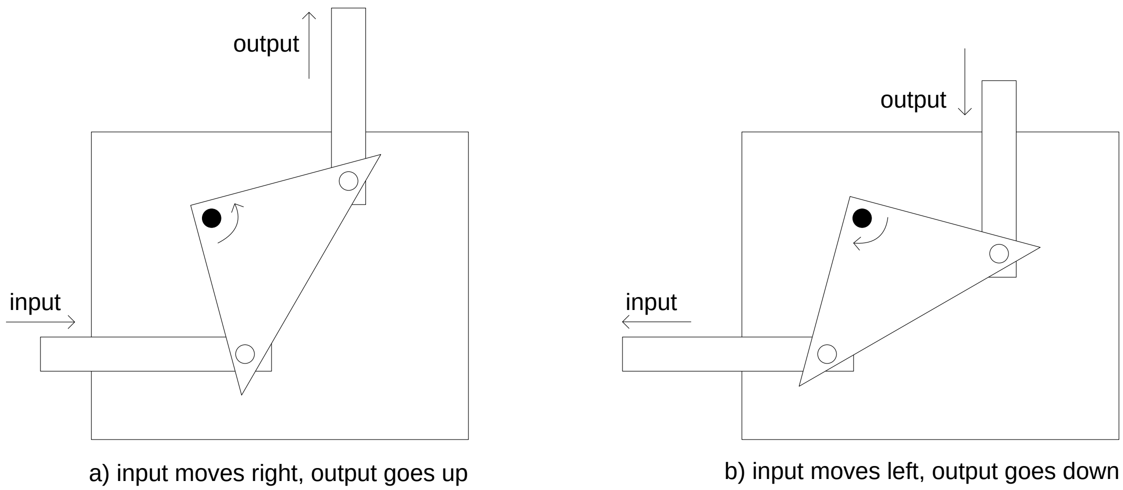


Figure 7: How a bent first-class lever makes input and output go at right angles

Technical Background

This lesson gets at the difference in directions of motion between first and third-class levers. In the language of levers, a fixed pivot is called a **fulcrum**. Figure 8 reveals the **first-class lever** at the heart of the Butterfly mechanism. Because the fulcrum is in between input and output, they have to go in opposite directions. To see why, imagine that the lever is glued to a circular pie plate, shown dashed in Figure 8, with the fixed pivot through the middle of both the lever and the circle. Let's think about what will happen when the plate turns around its fixed pivot. Because the input and output are at opposite sides of the circle, they have to move in opposite directions. See Figure 8

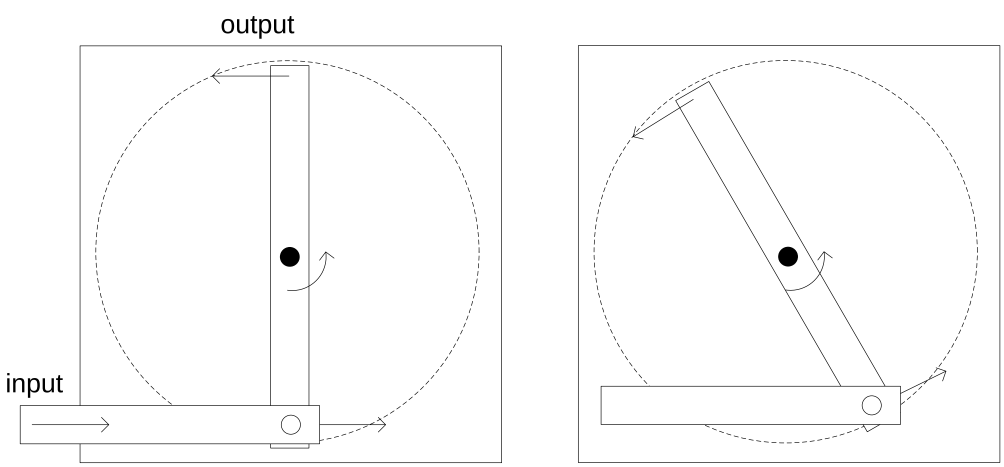


Figure 8: How a first-class lever is the key to the Butterfly-mechanism

Figure 9 is a similar diagram showing how the Hammer mechanism is based on a **third-class lever**. Here, the input is at one end, and the fulcrum is at the other. Because the input and output are on the same side of the fulcrum, they have to move in the same direction. Imagine again that the lever is attached to a pie plate, with the fulcrum through the center of the circle, but at one end of the lever. The circle is dashed in Figure 9. This time, the input and output travel together, because they are on the same part of the circle.

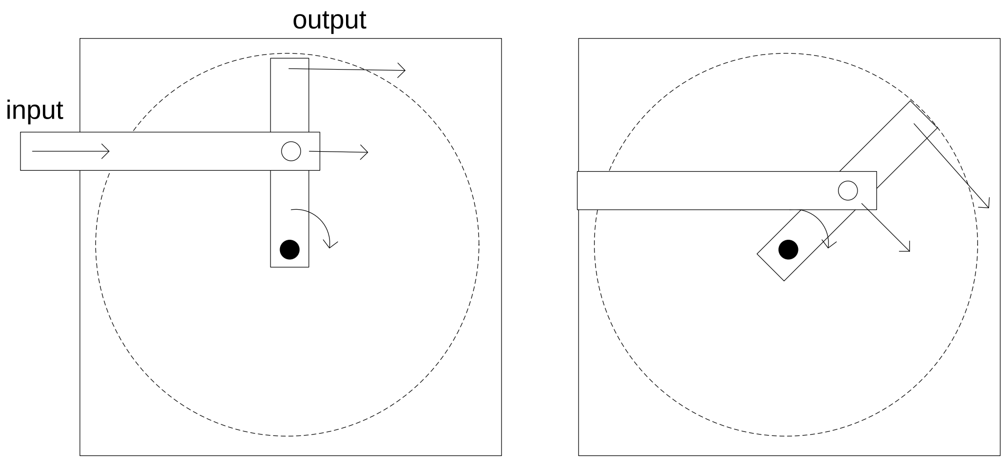


Figure 9: How a third-class lever is key to the Hammer mechanism

The **bent first-class lever** (see Extension) is sometimes called a bell crank, because it was the mechanism used for many years to ring a church bell. In Figure 10, the bell is stationary, and the bell crank is shown in gray. To ring the bell, a person would have to pull down on the long arm of the crank, which would force the short arm to the right, hitting the bell.

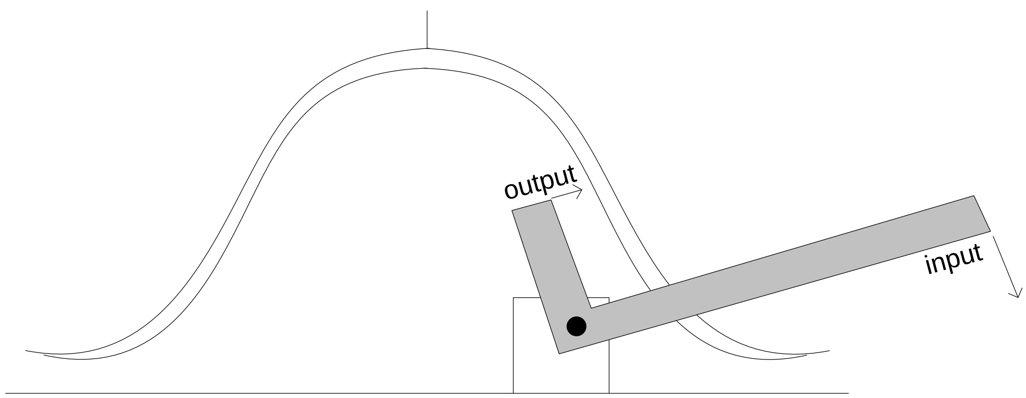


Figure 10: Bell crank and bell

To understand how the bell crank works, we'll again imagine that our lever is glued to a pie plate, with the fulcrum at the center, and think about what happens when the plate turns around its fixed pivot. Imagine that the input and output are attached to a pie plate by floating pivots, this time separated from each other by a quarter circle, as shown in Figure 11 a). Because they are only a quarter circle apart, they move at right angles to each other. The output moves up, as the input moves to the right, just like in Figures 6 and 7. Putting the input and output a quarter circle away from each other is the key to making a bent first-class lever.

Most of the circle isn't really necessary. It could be replaced by the bottom left quarter circle as in Figure 11 b), and would still work the same way. The quarter circle is nearly the same shape as a triangle, shown in Figure 11 c), as well as in Figures 6 and 7. In fact, even the whole triangle is not necessary. All the work is done by the two short sides of the triangle, which could be replaced by the L-shaped piece in Figure 11 d).

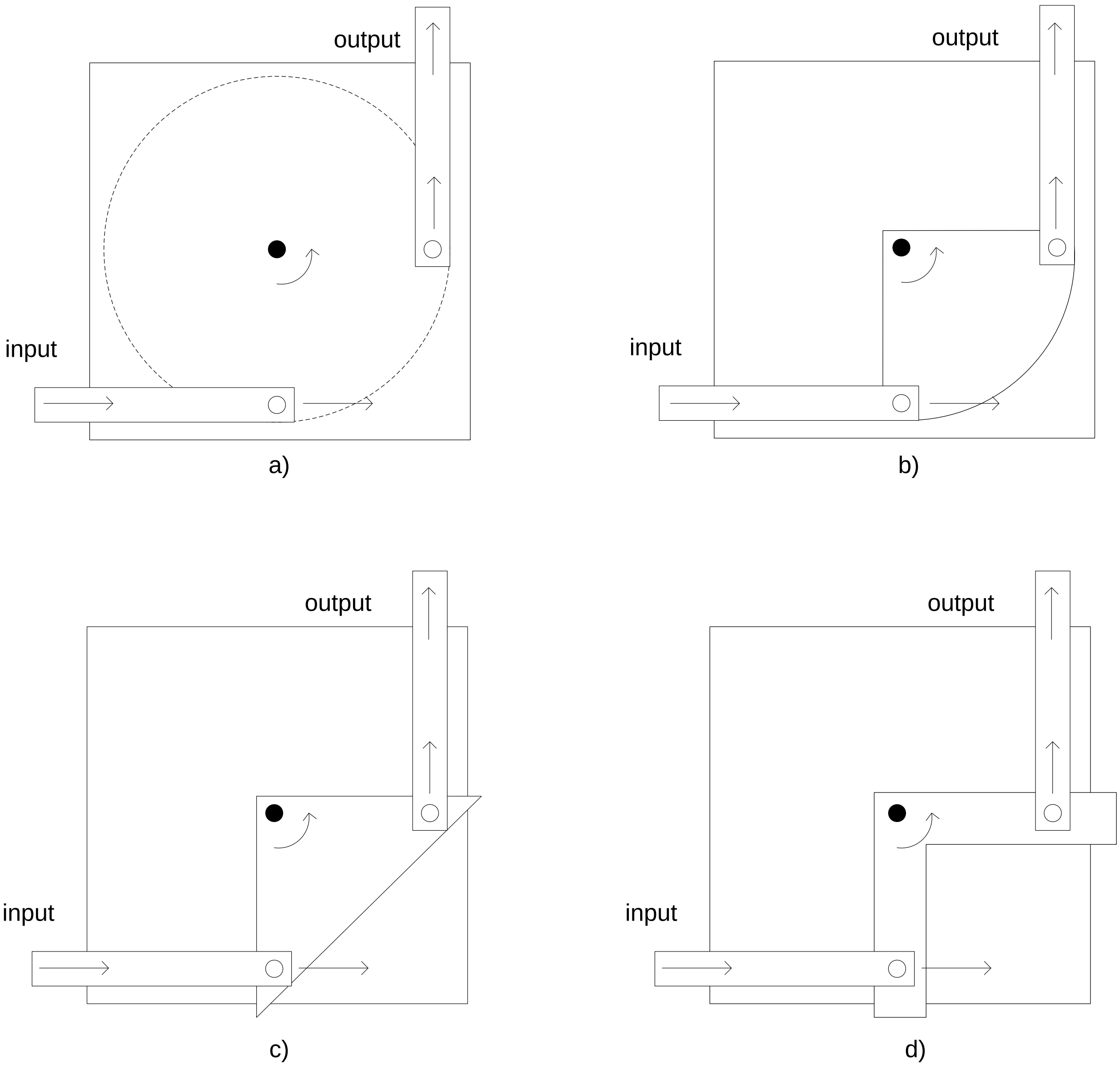


Figure 11: How to make a bent first-class lever

Glossary

Bent first-class lever: A lever whose fulcrum is in between the input and output, but in which the input, fulcrum and output do not lie on a straight line. It is also called a **bell crank**. See Figures 10 d) and 11.

Direction of motion: Path along which something travels; often indicated by drawing an arrow.

Lesson 6: Combining mechanisms

Overview

Students now build on the Hammer- and Butterfly-type constructions, as they learn to combine two mechanisms into one. They create pegboard mechanisms that feature a common input controlling two outputs, compare the directions of motion of the two outputs, and learn how a system can be built up from two simpler subsystems.

Materials

- ✁ **Windshield Wipers** and **Mouse-and-cheese** MechAnimnations – 6 of each
- ✁ **Pegboard bases, strips and fasteners**
- ✁ **Tape** & **Template for making mouse-and-cheese-cutouts** to attach to pegboard.
- ✁ **Science notebooks**

Procedure

1. **Windshield Wipers MechAnimation and Worksheet**. Demonstrate the <u>Windshield Wipers</u> MechAnimation several times. See Figure 1. What story is it telling?

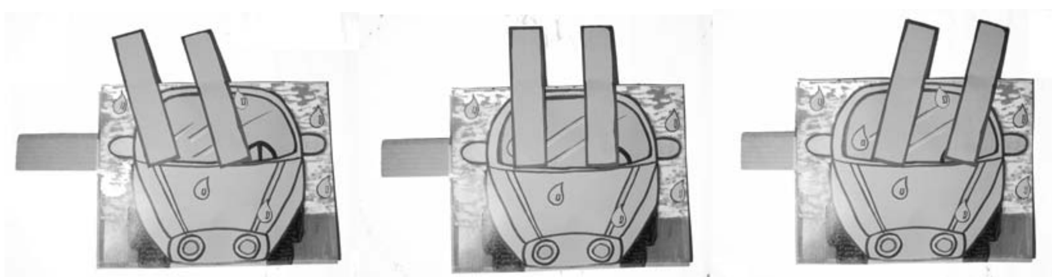


Figure 1: Windshield Wipers, showing output motion as input moves to the right

Ask students how many inputs and how many outputs there are, and where they are located. Then have them focus on the directions of motion. Distribute the <u>Windshield Wipers Worksheet</u>, and ask students to use arrows to show the directions of motion of the two outputs when the input moves to the right in item 1 a). Then they simply copy the arrows, one each, to 1 b) and 1 c). To complete Items 2 a) and 2 b), they could use their diagrams from Lesson 6 – these are just the <u>Hammer</u> and <u>Butterfly</u>!

2. **Mouse MechAnimation and Worksheet**. Demonstrate the <u>Mouse</u> Mech Animation (see Figure 2). What story is it telling?

Figure 2: Mouse MechAnimation, showing output motion as input moves to the right

Repeat Parts #1 & #2, this time using the Mouse MechAnimation and Mouse Worksheet (page immediately following Windshield Wipers Worksheet).

3. **Designing combined mechanisms**. Divide the students into two categories: Mouse people and Windshield Wipers people. Explain that they will first design their mechanism on paper, then make it, and (in the next lesson) create MechAnimations using these pegboard constructions as models. Be aware that the Mouse is the more difficult of the two. The information for designing each one is already on the Worksheet – all they need to do is combine the two diagrams in Part 2, into one diagram that uses the same input for both sides.

Science Notebooks

✁ Draw the diagram of what you plan to make.

4. **Making combined mechanisms.** Require that students have made their diagrams before beginning construction. Then provide pegboard materials, fasteners, and cutout figures of the mouse & cheese, for students to attach to their pegboard models.

5. **Whole-class discussion.** Review what students have made. Test them in front of the whole class, and ask students to comment on whether they work the same way as the Mouse or the Windshield Wipers. Explain that they have created a complex system from two simple subsystems, and congratulate them for doing so!

Science Notebooks

✁ Describe the mechanism you made.

✁ What problems did you have?

✁ How can you tell it works the same way as the original MechAnimation?

Outcomes

By combining two mechanisms, each with one input and one ouput, you can make a mechanism that has one input cont4rolling two outputs. If the outputs travel in the same direction (Windshield wipers), the two fixed pivots both have to be above or below the floating pivots. If the outputs travel in opposite directions (Mouse and cheese) one has to be above and one below the corresponding floating pivot.

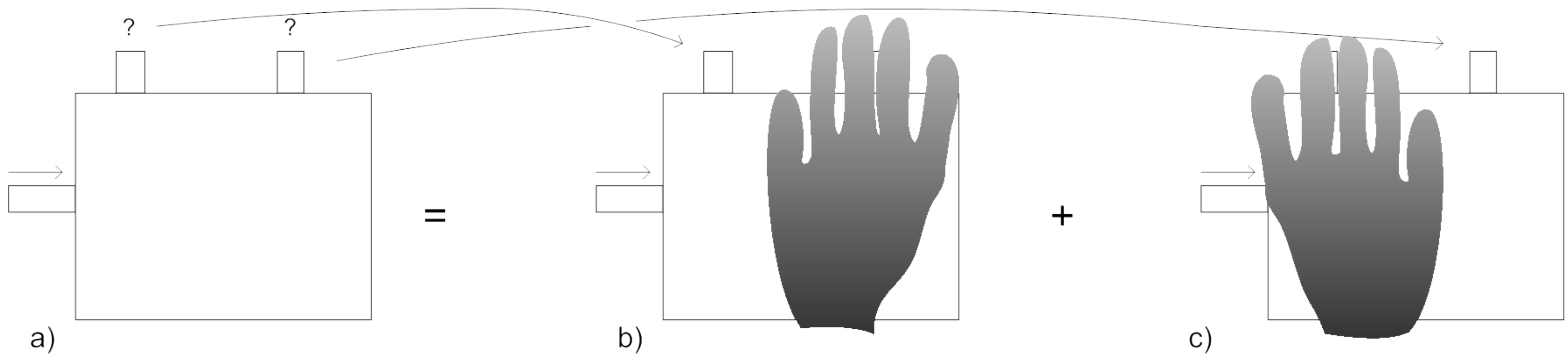
Assessment

Students should be able to create a mechanism that uses one input to control two outputs, and be able to explain how it works

Name: ___________________________ Date: ___________________

Windshield Wipers MechAnimation Worksheet

1. Look closely at the Windshield Wipers MechAnimation. Use arrows to show the directions of the two outputs in a), when the input moves to the right, as shown. Then copy the arrow from the left output to 1 b), and from the right output to 1 c).



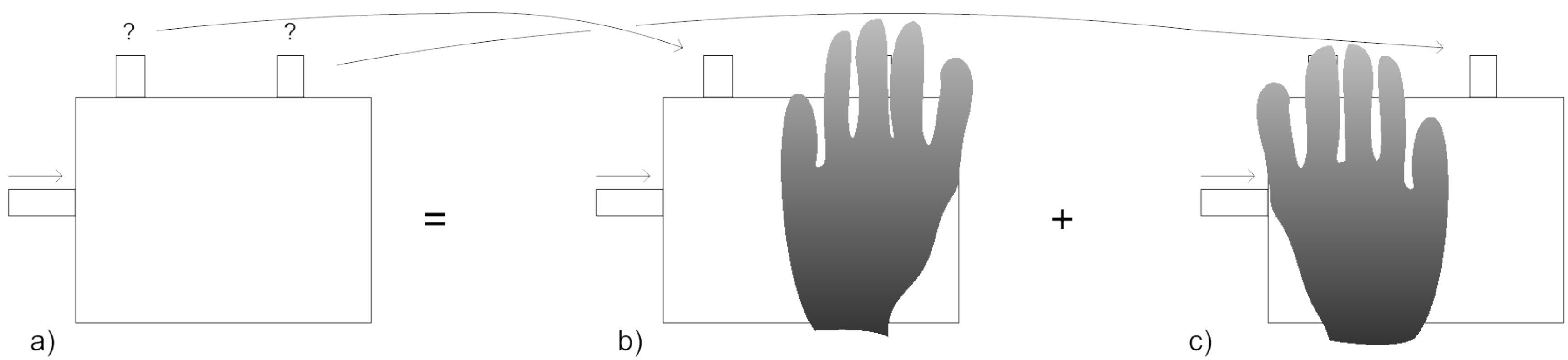
2. a) Make a diagram of a mechanism that would work like 1b):

b) Make a diagram of a mechanism that would work like 1c):

Name: ___________________________ Date: ____________________

Mouse-and-Cheese MechAnimation Worksheet

1. Look closely at the Mouse-and-Cheese MechAnimation. Use arrows to show the directions of the two outputs in a), when the input moves to the right, as shown. Then copy the arrow from the left output to 1 b), and from the right output to 1 c).



2. a) Make a diagram of a mechanism that would work like 1b):

b) Make a diagram of a mechanism that would work like 1c):

Extensions:

Some students may find the Windshield Wipers and Mouse-and-Cheese mechanisms easy to design and make, or may have already made them, and therefore need additional challenges. The “Which Way will it Move?” Worksheet (next page) asks students to predict how the outputs of various mechanisms will operate when the input of each one is pushed to the right. To see if their predictions were correct, students could build each one and test it. Figure 3 shows the input and output motions of some mechanisms they could try to create:

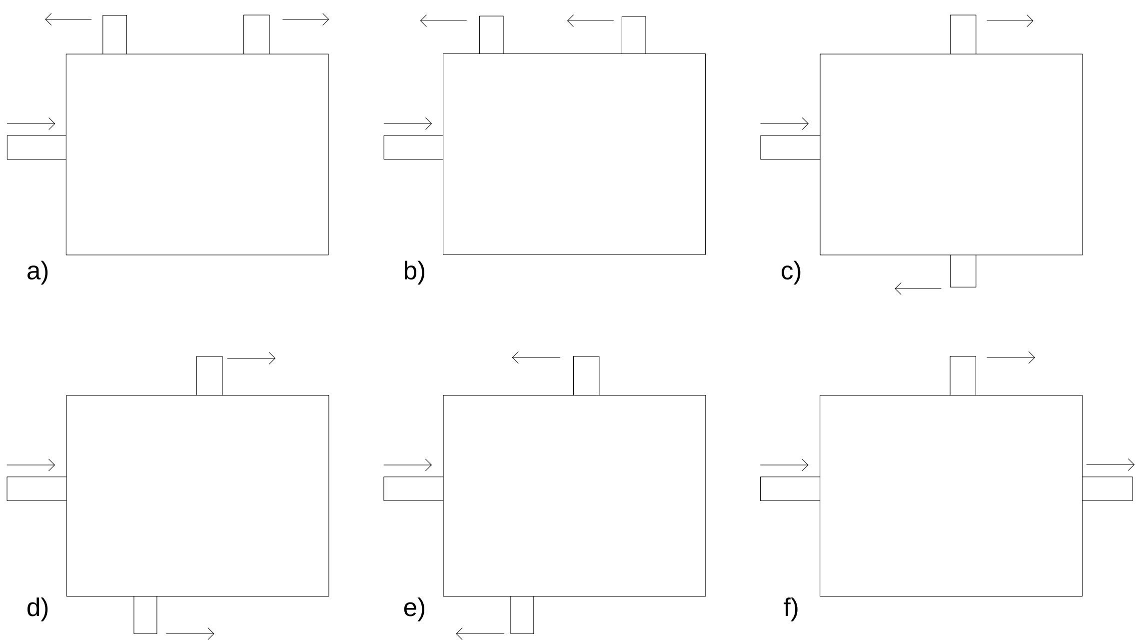
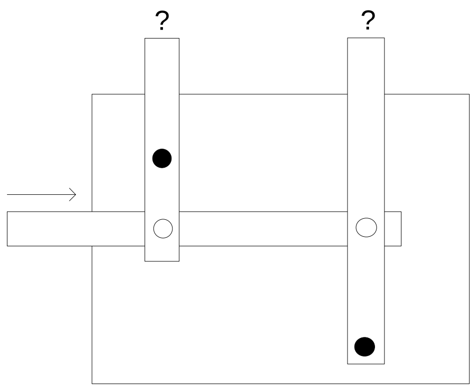


Figure 3: Mystery Mechanisms students could try to design and make

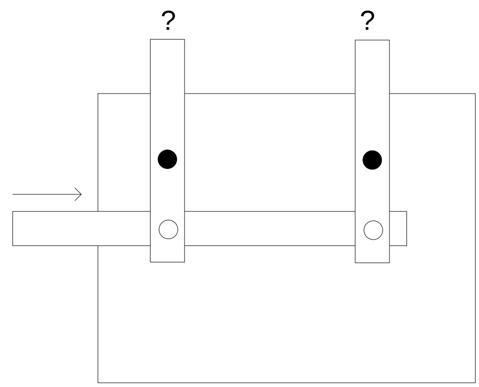
Name: ______________________ Date: ____________

Extension: Which Way will it Move?

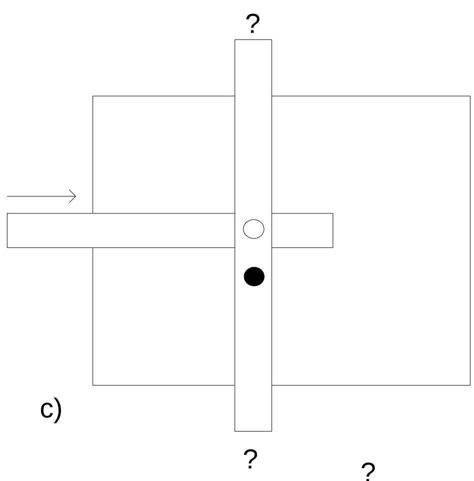
Use an arrow to show which way each output (marked by "?") will move when the input moves to the right.



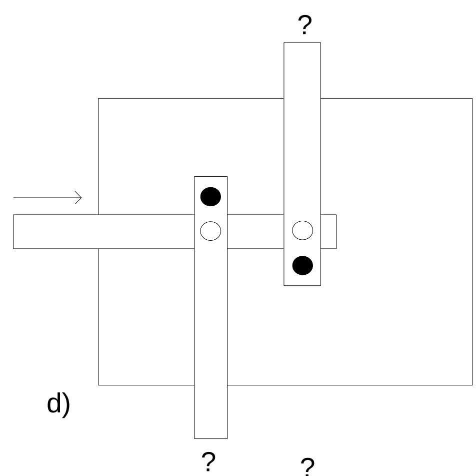
a)



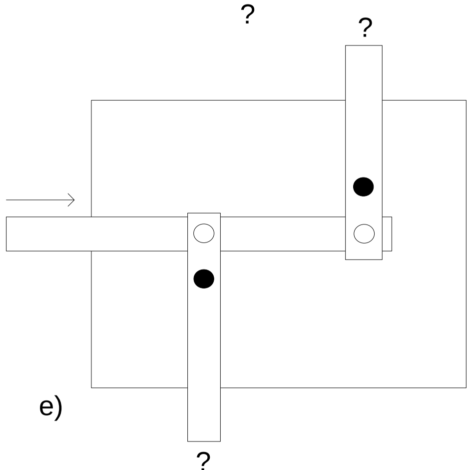
b)



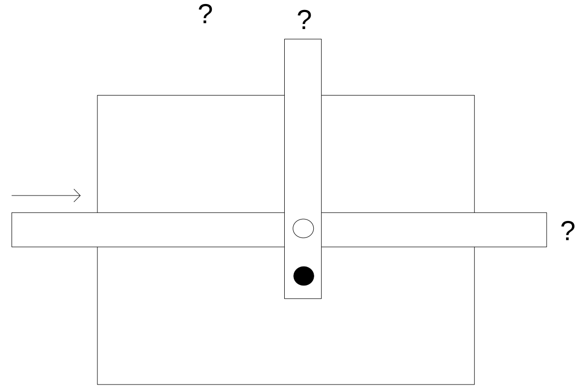
c)



d)



e)



f)

Troubleshooting

Students may not remember how they made the Butterfly and Hammer mechanisms. They can remind themselves by looking in their Science Notebooks, and/or by looking at examples from the previous lessons.

The key to understanding the Windshield Wipers is to see that both outputs move the same way, so they must both be made the same way. In the MechAnimation, both are Hammer-type mechanisms (third-class levers), because they output moves in the same direction as the Figure 4 shows how to combine two Hammer-type mechanisms (3rd-class levers) to make the Windshield Wipers:

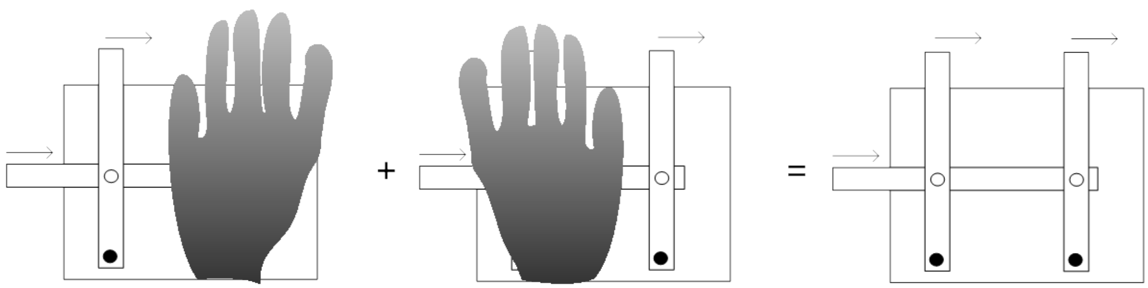


Figure 4: How two Hammer Mechanisms combine to make Windshield Wipers

The obvious difference between the Mouse and the Windshield Wipers is that in the Mouse the two outputs move oppositely. The left side of the Mouse is like the Hammer (and both sides of the Windshield Wipers), because it moves in the same direction as the input. However the right side moves the other way – opposite to the input – so it must be a first-class lever, like the Butterfly. Figure 5 shows how to combine a first-class lever and

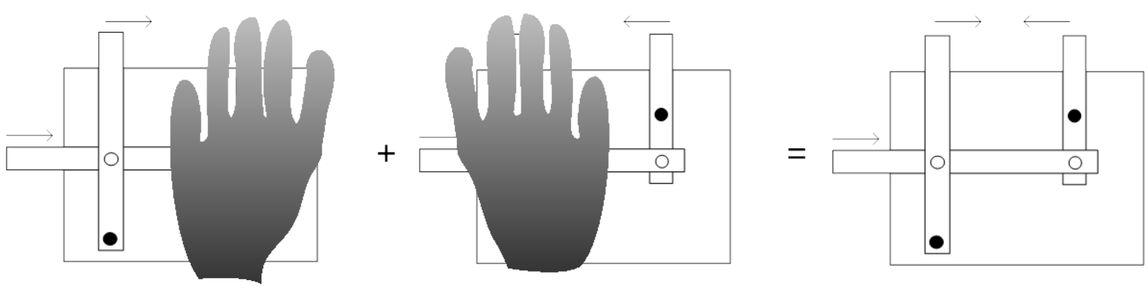


Figure 5: How to make a Mouse mechanism from a first- and third-class lever

Students may have difficulty seeing how to combine the two mechanisms into one. To demonstrate this possibility, select two mechanisms that have already been made in cardboard or pegboard. Lay one on top of the other so the two inputs coincide. Then demonstrate how the two outputs work together when the inputs are operated at the same time. See Figure 6. The photo on top left shows the mechanism whose output is on the left. Next to it is a mechanism with the output on the right. The two photos below show the same two mechanisms, one on top of the other, with the same input motion operating both. On the bottom left, the input is all the way to the left, and the ouputs are apart, while on the bottom right, the input is pushed toward the right and the outputs come together.

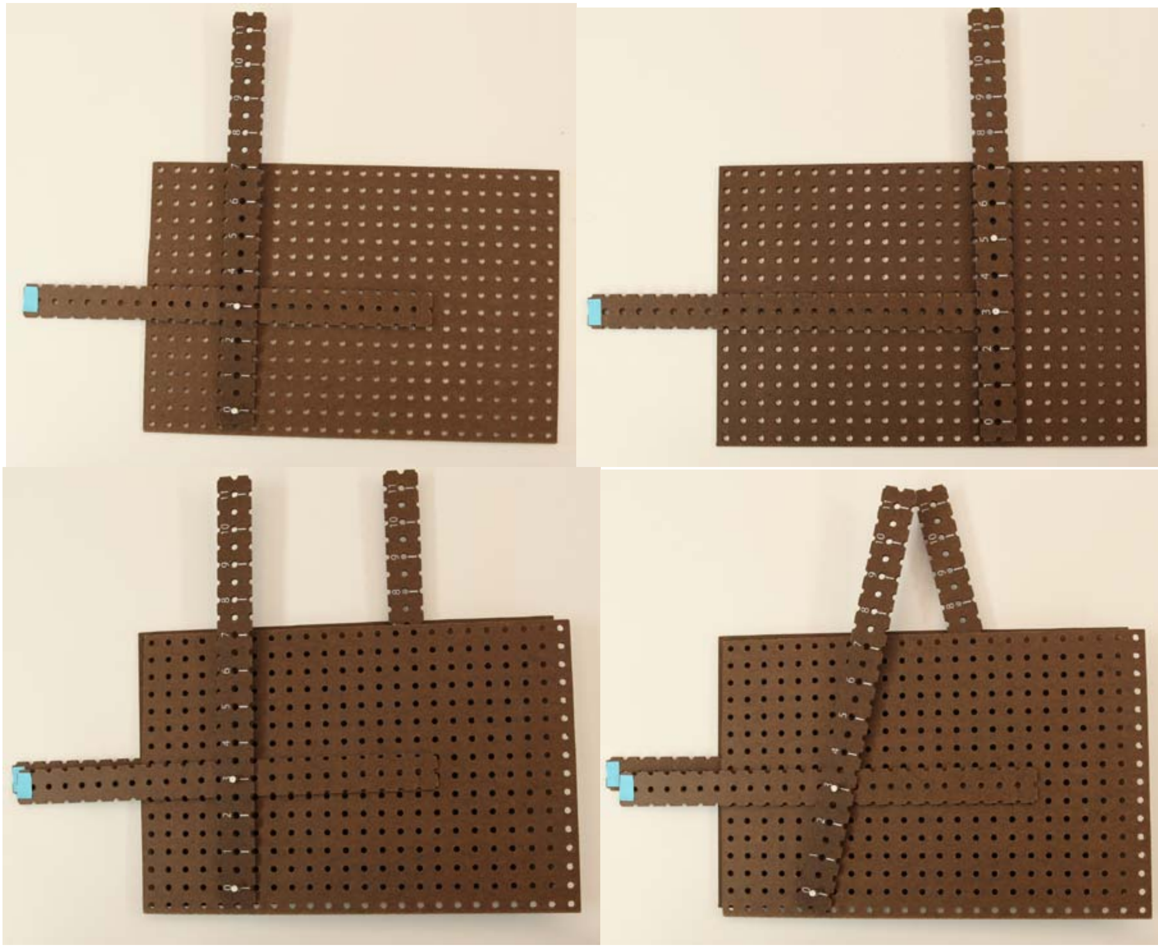


Figure 6: Two one-output mechanisms (top) are placed one on top of the other (bottom left), and then operated in tandem to work like a two-output mechanism (bottom right)

Then ask whether the two input links that you're operating together could be replaced by a single one. If you can move both input links with one hand, why not just move one, and attach it to both levers?

The Mystery Mechanisms challenges combine first- and third-class levers in various ways, with two levers in each case except f) controlled by a common input. See Figure 7.

Item f) is a little different from the others, because the "output" on the right is really just an extension of the input link. Another way to use these challenges would be as an assessment tool. The next page provides the same diagrams as in Figure 5, except that none of the output directions is labeled. Students are challenged to label the output direction by putting an arrow wherever they see a "?" Figure 5 could be used as an answer guide for this Assessment.

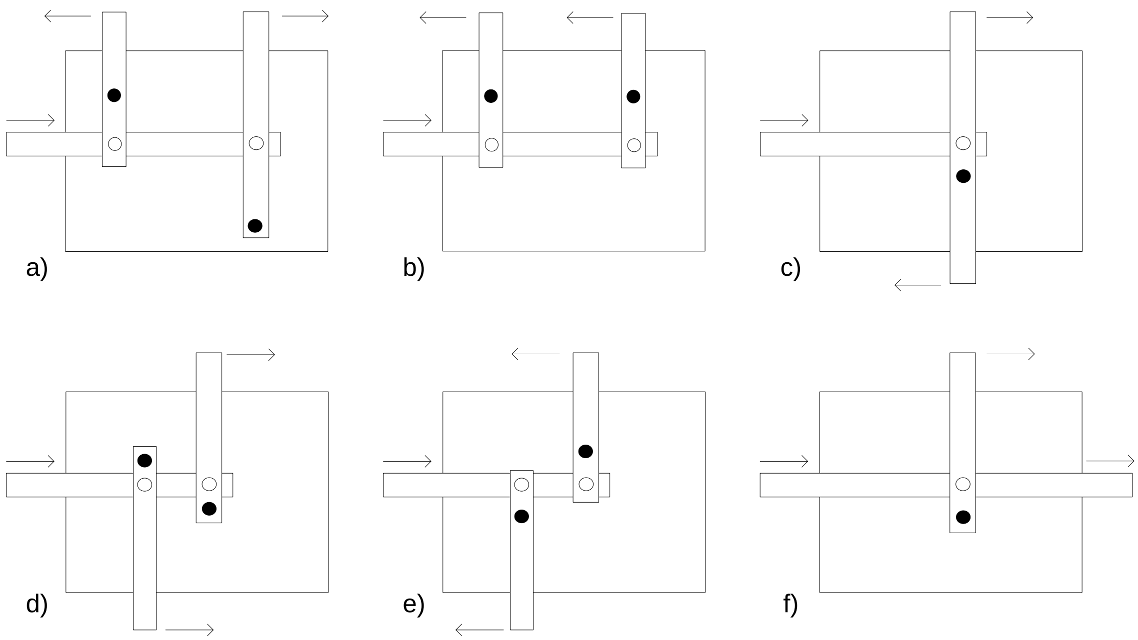


Figure 7: Solutions to Mystery Mechanisms challenges

Technical Background

Systems have been introduced in Lesson 2. This lesson distinguishes between a **simple system**, such as a lever with an input link, and a **complex system**, which is built from simple systems. When you combine two Hammer-type mechanisms to make **Windshield Wipers**, you are actually creating a complex system! Figure 8 shows a System diagram of the **Windshield Wipers**.

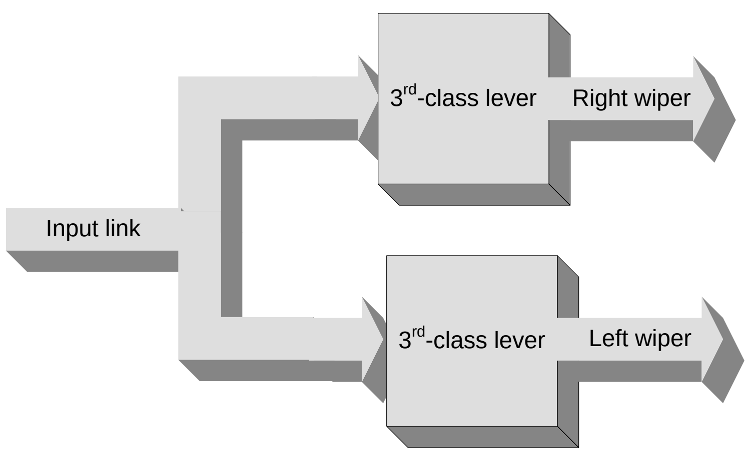


Figure 8: Windshield Wipers System Diagram

In the system diagram, each lever is represented by a box, because it could be a system by itself. When two levers are combined into a single system, the result is a complex system with two **subsystems**.

The Mouse is similar, except that the lever on the right is 1st-class; see Figure 9:

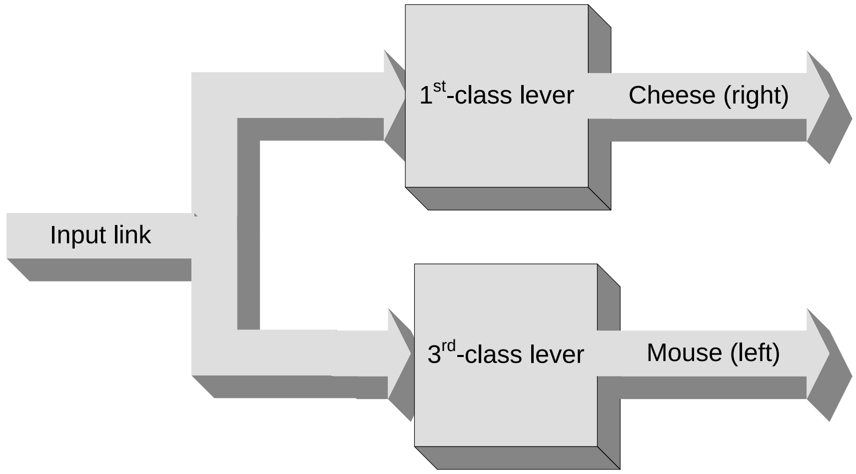


Figure 9: Mouse-and-cheese System Diagram

In both cases, the two subsystems share the same input, so they are operated in parallel – just like two lamps that are both connected across the same battery. Figures 8 and 9 are both diagrams of systems each with two subsystems in **parallel**. This just means that the input link is physically connected to both subsystems, i.e., both levers. The parallel connection is illustrated by a pair of scissors, which you normally operate by squeezing both handles together with your hand at the same time. By contrast, there are mechanisms that have one lever (subsystem) operating another, such as a nail clipper, so that the input to one is the output from the previous one. In that case, the two subsystems are said to be in **series**.

Glossary

Complex system: A system that can be subdivided into smaller units, each of which could be a system by itself.

Simple system: A system that cannot be broken into smaller subsystems.

Subsystem: A part of a larger system, which could itself be a system, because it has an input, and output and something that transforms the input into the output.

Series: Connection between two subsystems in which the output of one is the input to another.

Parallel: Connection between two or more subsystems that share a common input.

Lesson 7: Modeling Mechanisms

Overview

In this lesson, students create models of their mechanisms using disposable materials. They then use these examples to explore how a model can incorporate the most important features of the originals, without being an exact copy.

Materials

- **Pegboard mechanisms** students have made in Lesson 3
- **Cardstock,** 100 sheets
- **Paper fasteners –** box of 100
- **Science Notebooks**

Procedure

1. **Comparing materials: paper, cardstock and pegboard.** Distribute the mechanisms from the previous lesson. Provide each group with a few sheets of paper and a few sheets of cardstock, and ask them to compare it with ordinary notebook paper, as well as with pegboard. Ask the students,

   - *What would happen if I made a mechanism out of these other materials (paper or cardstock)?*
   - *What are the advantages of each material for making mechanisms? What are the disadvantages of each one?*

   Discuss the results by constructing a chart showing the pros and cons of each one. Develop the idea that a paper model probably wouldn't work very well, because paper is too flexible. A cardstock model could be stiff enough, but not nearly as strong as pegboard. However, cardstock is cheaper, so you could take it home. Pegboard is too expensive to take home.

2. **Modeling with cardstock**: Distribute additional cardstock and paper fasteners. Students should already have their original pegboard mechanisms. Their challenge is:

   Use cardstock and paper fasteners to create a model that works the same way as your mechanism. It should have the same input and output, and the inputs and outputs should move in the same ways as in the original mechanism.

   Students may ask how to make holes in cardstock. Here is a simple method:

   - Locate and mark where you want to make the hole on the cardstock.
   - Place the cardstock over a piece of corrugated cardboard or a soft rug. If neither is available, you can place the mark over a hole in a piece of pegboard.
   - Puncture the cardstock with a pen or pencil at the location mark. The cardboard, rug or pegboard hole will allow the pencil or pen to punch through.

   As students are working, help each one look at how well his or her model actually reproduces the motions of the original mechanism.

Science Notebooks

- How did you make your model?
- How is it different from the original?
- How are they similar?

3. **Understanding models**: In a brief whole-class wrap-up discussion, ask students for examples of models. They might suggest model cars, planes or boats; doll houses, clothing or furniture; stuffed animals; etc. If they don't include the mechanism models they have just made, ask if those should be added to the list. Then construct a class chart showing how each type of model is similar and different from the original.

Outcomes

Students should develop an understanding of what a model is and how a model can be useful. They should be able to construct an accurate cardstock model of a pegboard mechanism, and explain why the model is accurate.

Assessment

Describe the original mechanism and the model you made from it:

- What is each one made of?
- How are they similar?
- How are they different?
- What would prevent the model from working the same way as the original?
- What are some advantages of the original compared with the model?
- What are some advantages of the model compared with the original?
- How could you tell that your model is accurate?

Troubleshooting

It is likely that the input and output motions of the models will be quite different from those of the original. Some of the problems may be obvious: different numbers of links and pivots or failure to distinguish between fixed and floating pivots. To address these problems, suggest that students look closely at the original and the model to see if the configurations are the same.

If the basic motion is the same, but the amounts of motion are different, the locations of the holes are probably not accurate. This kind of problem is easy to detect by disassembling the cardstock model and laying it against the pegboard pieces to see if the holes line up. If the holes don't line up, here is a method for locating the holes accurately:

- Print or photocopy the Mechanism Diagram Template from Lesson 4 onto cardstock.

- ✁ Disassemble the pegboard mechanism, leaving a paper fastener or chalk mark to indicate the hole that was used for the pivot.
- ✁ Lay the pegboard piece on top of the cardstock template as shown in Figure 2, Lesson 4. Mark the hole on the cardstock with a pencil. Use the mark on the cardstock to make the hole, as described in Procedure, part 3.
- ✁ Cut the edges of the cardstock to match the pegboard.

Technical Background

Part 1 of the Procedure focuses on material properties. Everything is made of materials of one kind or another, and no two materials have exactly the same properties. They vary in cost, strength, color, water resistance, shininess, density and many, many other respects. What materials are chosen depends not only on these properties, but also on the purpose they will be used for. Table 1 compares pegboard and cardstock, as materials for making mechanisms.

Issue	**Pegboard**	**Cardstock**
holes	has them	has none
stiffness	Stiff – won't bend	Flexible – bends a lot
cost	Expensive – can't take it home	Cheap – you can use a lot of it

Table 1: Comparing pegboard and cardstock

In this lesson, an important property is **stiffness**, which describes resistance to bending or buckling. Take a long, thin strip of material, such as a ruler or meter stick. If you push *at right angles* to its own long axis, as in Figure 1 a), the less stiff it is, the more it will **bend**. Pushing *along* its axis will tend to make it **buckle**, particularly if it is not very stiff. See Figure 1 b).

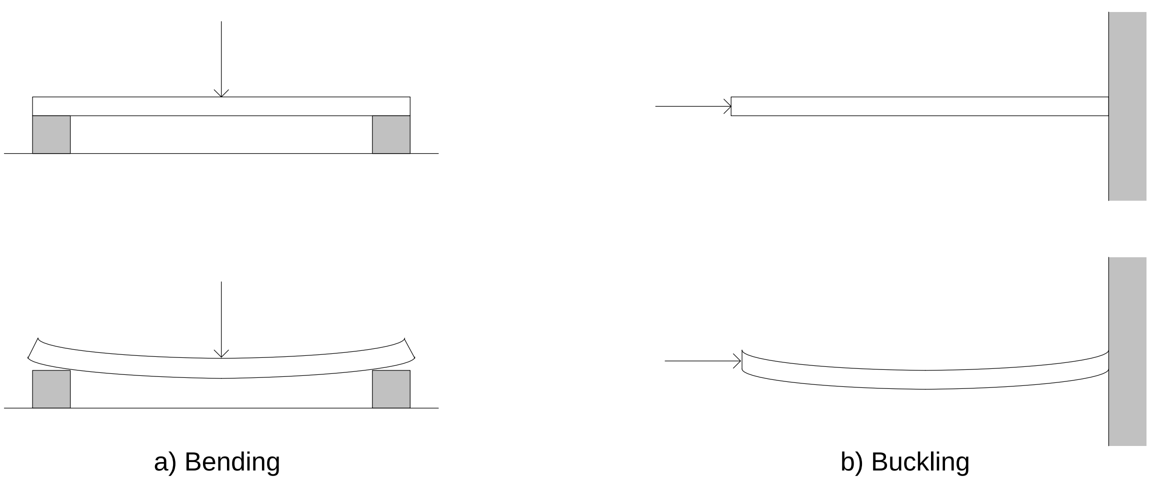


Figure 1: a) a beam in bending; b) a column in buckling

One big difference between bending and buckling is that bending increases gradually as the force or weight is increased, while buckling doesn't happen at all until a threshold is crossed, at which point it suddenly "kicks in" without warning.

No material is “perfect” in all respects, and there are always **tradeoffs**. For example, pegboard is stiffer than cardstock, and it already has holes, which makes it very handy for making mechanisms. However, it is too expensive to give away. Cardstock is much cheaper, though somewhat harder to use. Every time you choose a material (or make any other design choice), you gain something, but you also give up something. In engineering, you can’t get something for nothing. The tradeoffs you make in any situation depend on your priorities at the time.

A model is a simplified version of something, which coincidentally illustrates the concept of tradeoffs. When you make a model, you are keeping *some* of the characteristics of the original, while leaving out others. Which characteristics should you keep? That depends on the purpose of the model. A model car is supposed to *look like* a real car, and usually *roll* like one, while costing a lot less and taking up a lot less space. Unlike real cars, most models are also not self-propelled. There are tradeoffs here too, if your question is whether to select the model or the real thing.

In Part 4 of the Procedure, students consider different kinds of models, including the cardstock models they have made of their pegboard mechanisms. Table 2 shows possible entries in the chart showing examples of models:

Original	**Model**	**Similarities**	**Differences**
Real car	toy car	Made of metal, both can roll	Real Car is bigger, goes by itself
Real house	doll house	Doors and windows	Real house is bigger, has lights and water
Real animal	Stuffed animal	Look similar	Different materials, real animal is alive
Doll	person	Look similar	Different sizes and materials, real person is alive and usually bigger
Pegboard mechanism	Cardstock mechanism	Inputs and outputs move the same way	Pegboard is stronger, harder to bend

Table 2: The Model vs. the Real Thing

An interesting question could arise:

> *If I make two mechanisms that work the same way, one in cardstock and one in pegboard, which is the “model” and which is the “real thing?”*

This is a very good question, which would be answered differently under different circumstances. If the pegboard mechanism was the final product, and you wanted to demonstrate to someone else how it worked, you might use a cardstock model. On the other hand, if your goal was to create a MechAnimation, and you wanted to try out different arrangements of the links and pivots, you could definitely use a pegboard model for this purpose.

Glossary

Beam: Long, narrow structure, subject to buckling

Bending: Gradual sagging of a beam due to a weight or other force or applied at right angles to its long dimension; see Figure 1 a).

Buckling: Sudden "giving way" of a material due to a weight or other force or applied along its long dimension; see Figure 1 b).

Column: Long, narrow structure, subject to bending

Model: A 3D representation of something that captures its most essential features, while leaving out details that can be added later.

Stiffness: Resistance of a material to buckling or bending; the opposite of **flexibility**.

Tradeoffs: Alternative choices in design, such as whether to select a material that is stiffer or one that is cheaper.

Lesson 8: Making a MechAnimation

Overview

Based on what they have learned in previous lessons, students design and make their own MechAnimations. As they do so, they keep records both of what they have done, and also of issues or problems they have encountered. Some of these issues are likely to be addressed in the following two lessons. Then they will have an opportunity to revise their designs.

Materials

- ✁ **Pegboard bases, strips and fasteners** for modeling the mechanism of a MechAnimation
- ✁ **Cardstock –** 100 sheets
- ✁ **Paper fasteners –** 2 boxes of 100 each
- ✁ **MechAnimation**
- ✁ **Post-Its**™
- ✁ **Markers & craft materials** for decorating MechAnimations
- ✁ **Science notebooks**

Procedure

1. **What is a MechAnimation?** Demonstrate one of the MechAnimations. Ask:
   - ✁ *What is a MechAnimation?*
   - ✁ *What does it show?*
   - ✁ *How is seeing a MechAnimation in action different from simply telling the story (such as, "A Hammer hits a nail")?*

   Develop the idea that a MechAnimation **uses a mechanism** to animate **a story.**

2. **Designing a MechAnimation.** Distribute the pegboard mechanisms that students have already made in Lesson 6. How could these help them in designing in MechAnimation? In Lesson 7, we used cardstock to make a model for a pegboard mechanism. Could the roles be reversed? Could you use pegboard to model a mechanism that you would later make in cardboard? It's easier to use than cardboard, because it already has holes in it. Develop the idea that the pegboard mechanism could be a **model** for the MechAnimation.

Science Notebooks
✁ Write down the story you would like your MechAnimation to tell.
✁ Make a drawing showing the story.
✁ Make a diagram of the pegboard mechanism that will be the model for your MechAnimation.

3. **Making a pegboard model.** Provide pegboard bases, strips and fasteners. Each student will use his or her diagram to make a pegboard model of the mechanism for the MechAnimation.

4. **Making a MechAnimation.** Provide blank cardstock, markers, paper fasteners, tape and craft supplies. Students are to create their MechAnimations based on their designs.

5. **Whole-class discussion; listing issues.** Convene a whole-class meeting to provide an opportunity for students to demonstrate the MechAnimations they have made. Chart a list of the issues that have come up. Examples of issues might be:

   - ✁ Parts are too hard to move;
   - ✁ Input crumples when I push it;
   - ✁ Pieces get in each others' way;
   - ✁ Paper fasteners get hung up on each other;
   - ✁ Outputs don't move in the direction I want them too;
   - ✁ One output moves further than the other.

Tell students that in the next few lessons, they'll learn how to address most of these issues.

Outcomes

Students should be able to design and make a MechAnimation that conveys the story they want it to tell.

Assessment

Each student should be able to describe how his or her MechAnimation works, and explain the process of designing it.

Troubleshooting

A major issue that comes up in making a MechAnimation is **interference**, meaning that one part gets in the way of another. Watch closely as you try to operate it, and you can usually see what's getting in the way of what. Here are some common intereference problems and their remedies:

- ✁ **The ears of one paper fastener get hung up on another paper fastener.** A simple solution is to turn one of the paper fasteners around, so its ears are on the opposite side of the cardstock parts. See Figure 1.

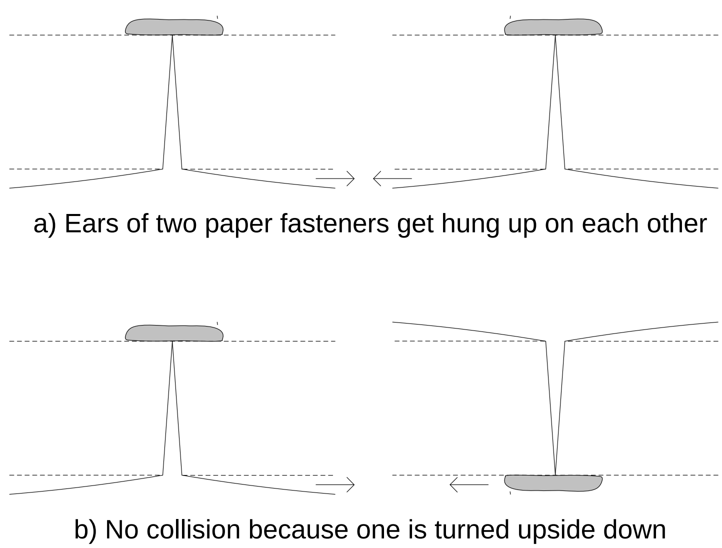
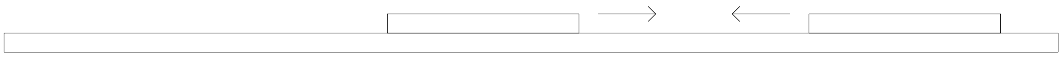
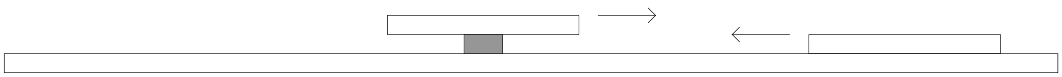


Figure 1: Solving an interference problem by turning one paper fastener upside down

✁ **Two outputs get in one another's way.** This problem can be solved by raising one of the outputs so it is on a different level from the other. A little piece of cardstock can be used as a standoff to lift one of the outputs so it can slide over the other. Figure 2 shows an <u>end view</u> (looking down the strip from its very end), showing how a standoff can elevate one link above the other.



a) Interference as two outputs collide



b) Stand-off (shaded) used to lift one output, so it can slide above the other

Figure 2: Edge view of a pegboard mechanism, showing how to use a standoff to prevent collision between outputs

✁ **Construction turns a mechanism into a structure.** The problem here is to control two 3rd-class-lever outputs, one directly above the other, from the same input, as in the mechanism design challenge of Figure 3.

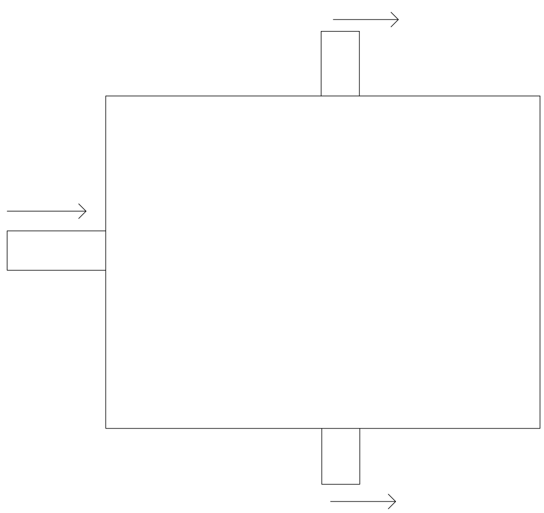


Figure 3: Design challenge: two outputs in same direction as input

Figure 4 a) shows an idea that doesn't work. Lever X, slightly enlarged and outlined with a dashed line, is attached by the fixed pivot shown as a shaded circle. It is attached to the base <u>under</u> lever Y, and so its fixed pivot does not interfere with lever Y. However, the same is not true for lever Y's fixed pivot. Because lever X is under it, lever Y's fixed pivot has to pass through lever X as well as lever Y, preventing X from moving at all. This second pivot becomes a pin, which turns X into a structure, not a mechanism! To solve this problem it's necessary to move one of the levers so that the two fixed pivots attach only one lever each, as in Figure 4 b).

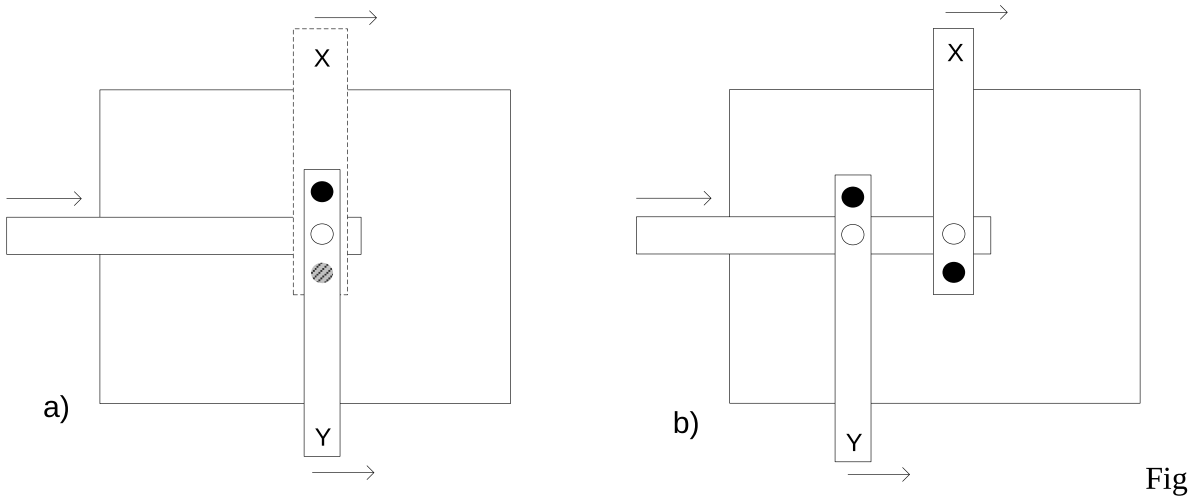


Figure 4: a) doesn't work because two fasteners turn X into part of a structure;
b) problem is solved by separating levers X and Y

✂ **Two levers try to force a single floating pivot to move in two different directions.** A more subtle problem occurs in the mechanism design challenge of Figure 5.

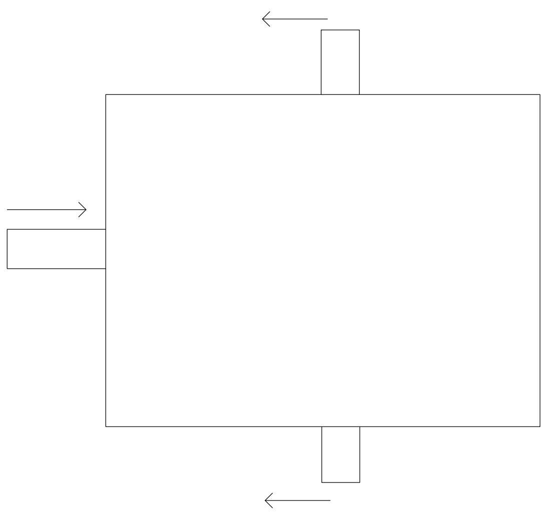


Figure 5: Design challenge: Two outputs in opposite direction from input

Here, the proposed solution in Figure 6 a) appears to work, and actually does work pretty well if the mechanism is made in cardboard. However, if the mechanism is made in pegboard, the input and outputs will be difficult or impossible to move. The magnified views of levers X and Y in figures 6 b) and c) explain why. The movement of lever X in 6 b) requires the floating pivot to move in an upwards arc (curved arrow), while the movement of lever Y in 6 c) forces movement of the same floating pivot in a downwards arc (curved arrow).

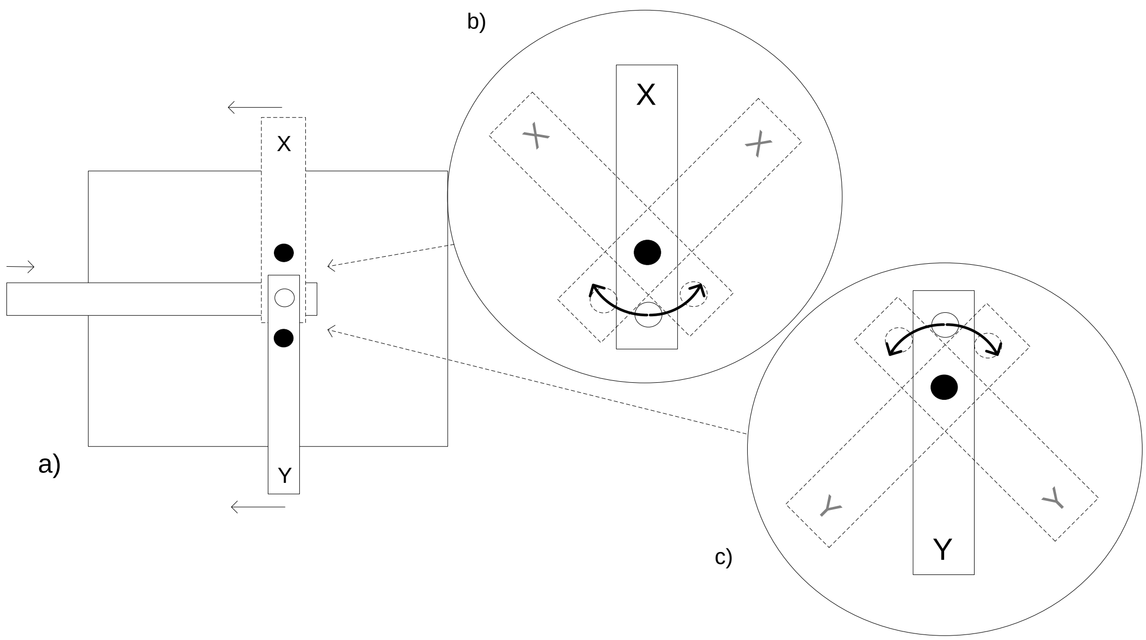


Figure 6: a) requires movement of the floating pivot along two different paths, shown by curved arrows in b) and c)

In pegboard, the floating pivot can't move along two different paths at the same time, so the input (and therefore outputs) get hung up. In cardboard, it's possible to make it move, because the pivots aren't nearly as tight and the cardboard can bend a little too. You can make it even easier by cutting out slots for the pivots.

A solution similar to Figure 4, but adapted to 1st-class levers, also works here. Figure 7 shows how to separate the two output levers X and Y, by adding another floating pivot. The problem isn't completely solved, because the input link still has to move in somewhat different directions for the two levers, but there is enough flexibility in the pegboard, and room in the holes, to allow free movement over some range.

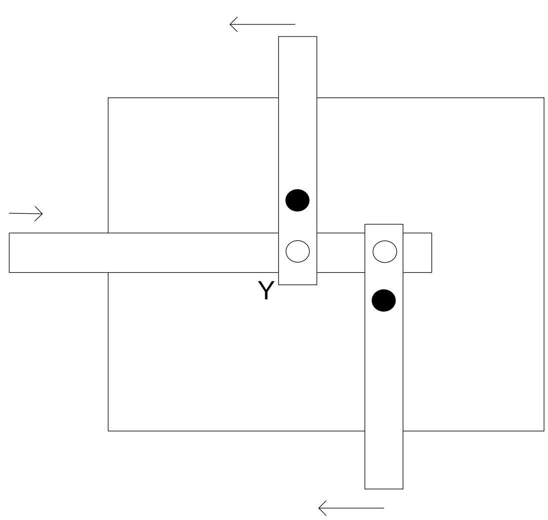


Figure 7: Two 1st-class levers operated by common input

Technical Background

Interference describes the situation that occurs when one part of a mechanism gets in the way of another. They can't both be in the same place at the same time, so the mechanism gets stuck at that point. In Figure 1 a), there is interference between two paper fasteners, and Figure 2 illustrates interference between two links. The solution in both cases requires redesign, to keep the parts from colliding, and therefore allow them to move past each other.

The example in Figure 4 occurs because of a less obvious form of interference. The two levers do not interfere with each other directly, because lever Y is above lever X, but the fixed pivot for Y has to pass through X. However, X already has a fixed pivot so the second fastener, as discussed in Lesson 2, turns X into part of the structure with the base. The interference is between the fixed pivot for lever Y, and its location through lever X, which cannot remain a mechanism if it has another fastener through it.

The case shown in Figure 6 is more subtle still. To understand the problem, it's useful to review the distinction between a line and an arc. A **line** is not only the shortest distance between two points, it is also the only path that permits the shapes on either side to show **symmetry**. Figure 8 shows a simple experiment that reveals the relationship between a straight line and a type of symmetry called **mirror symmetry**:

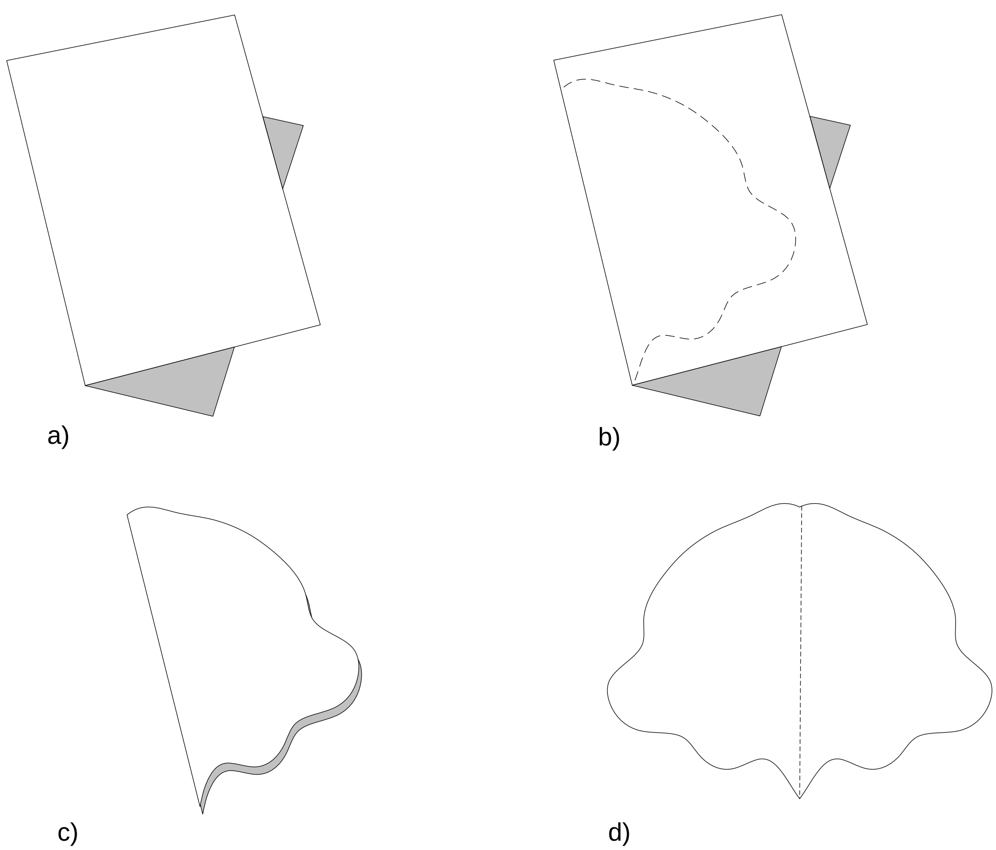


Figure 8: What's special about a straight line: a) Fold; b) draw any curve that covers both sides of the fold; c) cut out along the curve, and d) open and compare the two sides

Take any piece of paper. Fold it once, somewhere near the middle, as in Figure 8 a). Draw a curve that will cover both the top and bottom of the fold (b), and cut both top and bottom along the curve (c). Then unfold the paper, as in 8 d), and compare the two sides. They will be the same size and shape, except that one side will extend from the fold towards the right, and the other side will extend from the fold towards the left – they are mirror images of each other. The only possible shape of the fold line that can make the two sides equal and opposite is a straight line. Any other path would create different shapes on either side. A line that divides two shapes that are symmetrical is called a **line of symmetry**.

This observation applies to the mechanism in Figure 6 a), which is reproduced in Figure 9. Both levers, X and Y, should move in the same way. For that to happen, the input link, and therefore the floating pivot, would have to move along a line of symmetry, shown as a dashed line in Figure 9. Unfortunately, in the mechanism in Figure 9, the floating pivot cannot actually move along the line of symmetry, because the two levers try to force the input link to move in different paths.

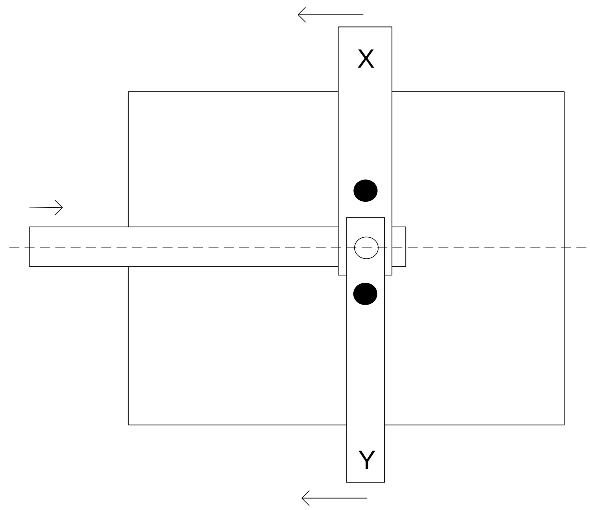
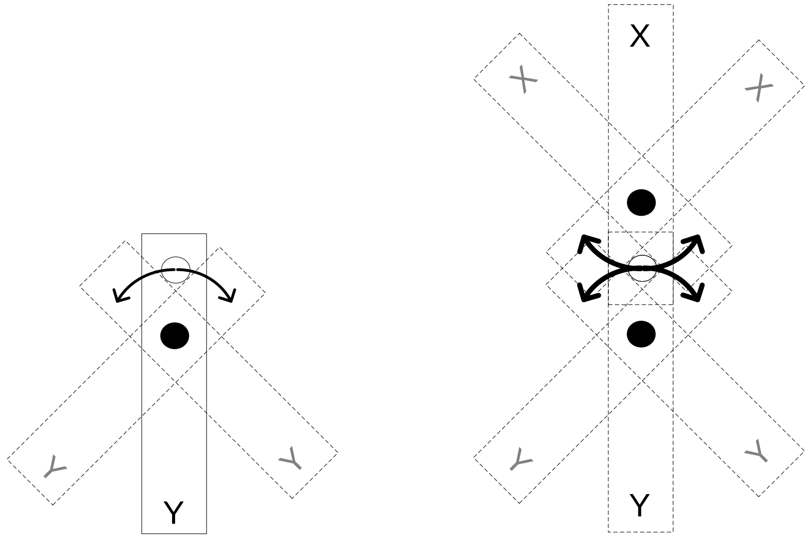


Figure 9: Mechanism of Figure 6, showing line of symmetry (dashed)

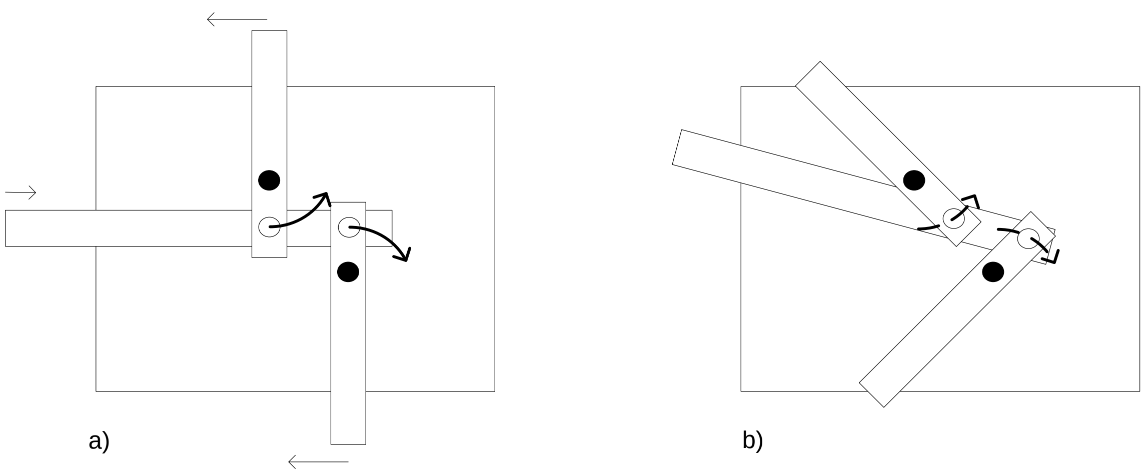
An **arc** is a path that could be part of a circle. Any point on a link that is attached by a fixed pivot has to travel in an arc, because the fixed pivot acts like the center of a circle, and the link keeps the point a constant distance from the center of the circle. Any point on either of the levers in Figure 9 travels in an arc, rather than a straight line, because it is forced to by the fixed pivot. Figure 10 a) shows again (as in Figure 6 c)) how lever Y tries to make the floating pivot follow and arc. The problem is that lever X also wants the same floating pivot to follow an arc, but it can't be the same arc! It can't be, because only a straight line would maintain the symmetry between the top and bottom, as discussed above. The two arcs are emphasized in Figure 10 b).



a) b)

Figure 10 a) shows the arc traveled by lever Y; b) superimposes the arcs traveled by X and Y

The solution proposed in Figure 7, and reproduced in Figure 11 a) works somewhat, but not perfectly. The two floating pivots still have to travel in arcs, but now the two arcs are separated. In order to follow both arcs simultaneously, the input link actually has to tilt, as shown in Figure 11 b). Even though the two floating pivots are separate, the input link still can't follow the line of symmetry, due to the mismatch in motion above and below it.



a) b)

Figure 11: In order to follow the two arcs in a), the input link has to tilt, as shown in b)

Glossary

Arc: a curved path that follows part of a circle

Interference: collision that occurs when two parts are in each others' way

Line: a straight path that allows symmetry between the shapes on either side

Line of symmetry: A line that divides two shapes that are symmetrical to one another

Mirror symmetry: a type of symmetry which preserves the same shape on either side of a line of symmetry, but reverses right and left

Symmetry: a relation between objects, which all have the same size and shape, but different locations and/or orientations

Lesson 9: Controlling how far things move

Overview

This lesson compares the distances traveled by inputs and outputs. Students examine the Frustrated Butterfly net MechAnimation, which looks like the original one, but the net travels too far over the butterfly, missing it completely. To uncover the problem, students experiment with pegboard to see how the location of the fixed pivot affects how far the output travels.

Materials

- Six **Frustrated Butterfly Net MechAnimations –** one per group
- **Pegboard bases, strips and fasteners**
- **Template for making butterflies and nets**
- **Science notebooks**

Procedure

1. **Demonstration of MechAnimations.** Show the students the Frustrated Butterfly Net MechAnimation, with the net vertical (Figure 1, left) so it is far from the butterfly. Ask them to predict what will happen when you operate the input. After they have made their predictions, operate it several times, and ask for their reactions.

Figure 1: Frustrated Butterfly Net MechAnimation

2. **Making a Butterfly**: Divide the class into groups, and provide each student with pegboard materials and fasteners, and cutout butterfly and net figures. Explain that everyone will be making butterfly mechanisms. They should begin by making the same kind of mechanism as in Lesson 6: The input and output will have to go in opposite directions, so the fixed pivot will be above the input link. Tell students that to start with, they should put the fixed pivot just above the input link. Then they should attach the cutout figures: the net attaches to the top of the lever, and the butterfly attaches to the base, as in Figure 2, left. Next they should operate the input to see what happens. See Figure 2, right.

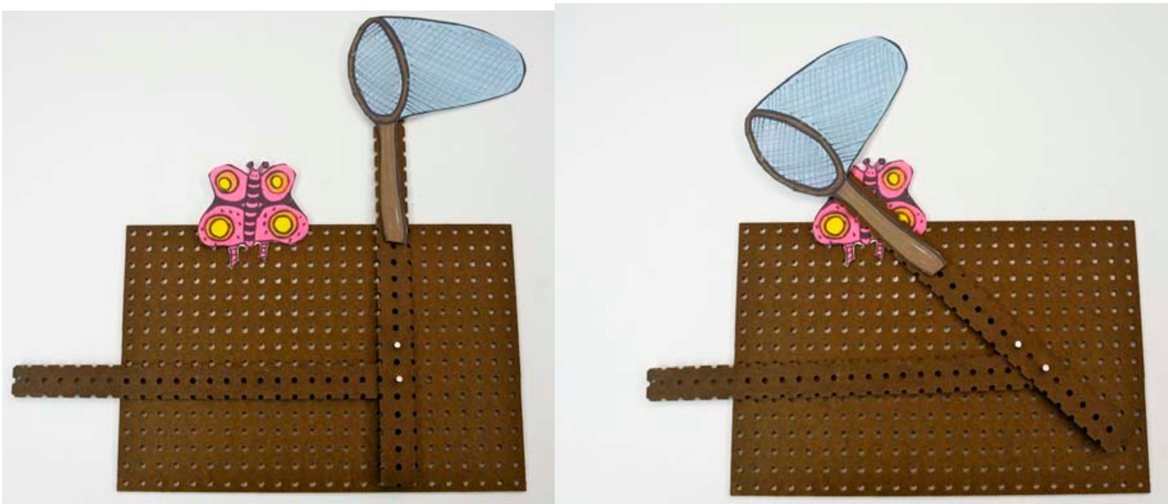


Figure 2: Pegboard model of Frustrated Butterfly Net MechAnimation with net up (left) and down (right), showing the net passing over the butterfly

<u>Science Notebooks</u>:

✁ Make a **diagram** showing what a <u>Butterfly-net</u> MechAnimation **should** do.

✁ Make **another diagram** showing what the <u>Frustrated Butterfly-net</u> MechAnimation **actually** does.

✁ **Describe** the problem with the <u>Frustrated Butterfly-net</u>.

3. **Brainstorming about how to fix the problem:** Conduct a whole-class meeting to brainstorm ideas about how to solve the "Frustrated Butterfly Net" problem:

   ✁ *How could they change the mechanism to make the net catch the butterfly?*

   Mini-lesson on arcs and circles: If students don't think of moving the fixed pivot, develop this idea by demonstrating what happens when you …

   1. … rotate your arm at your shoulder,
   2. … rotate your forearm at your elbow, and
   3. … rotate your hand at your wrist.

      Ask students to try each one and compare how much their hand moves each time. Then ask:

   ✁ *Where was the fixed pivot each time?*

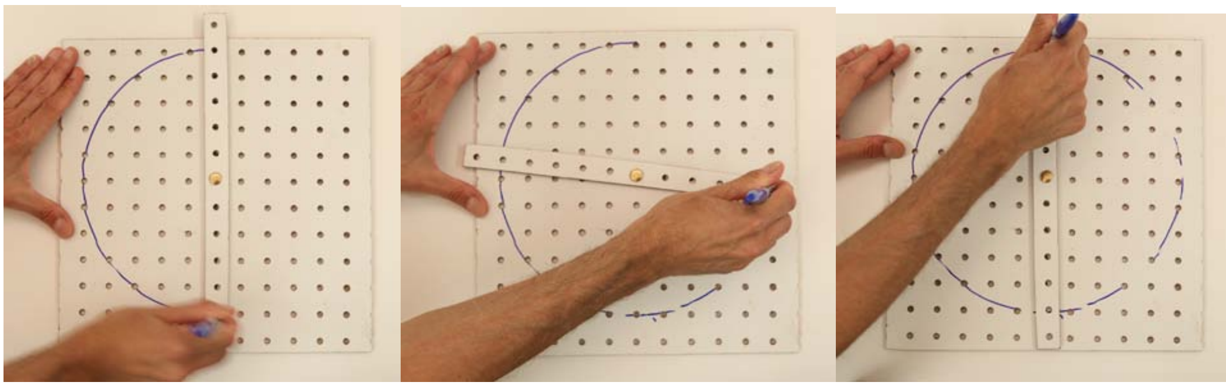
   ✁ *Where should the fixed pivot be to get the most amount of movement?*

   ✁ *Where should it be to get the least amount of movement?*

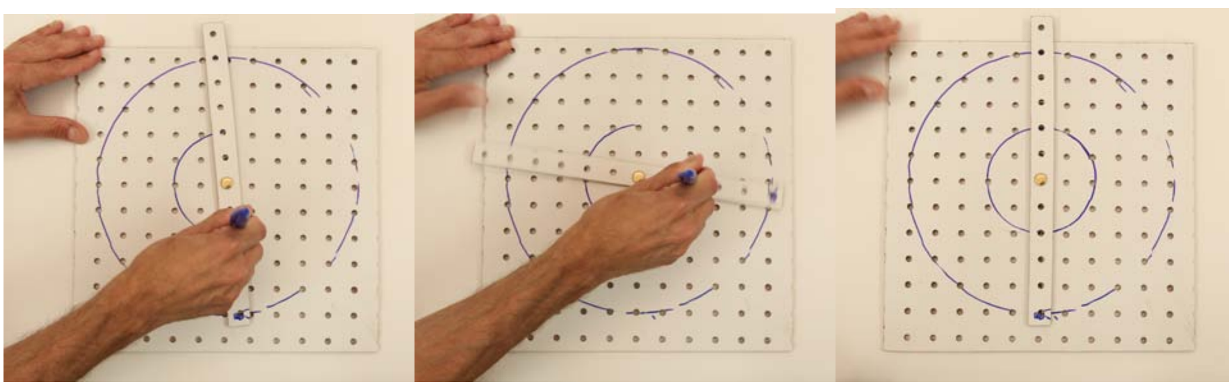
   To develop the idea further, make a demonstration compass by attaching a strip of pegboard to a base with a fixed pivot and placing a marker through one of the furthest holes, and rotating the strip around your finger so the pencil draws a complete circle. See Figure 4 a).. To make the circle more visibile, use a fluorescent marker, or put a piece of cardstock under the link.

Then ask students:

- *If I use this hole for my marker (indicating a hole that is closer to the fixed pivot), will the marker still draw a circle?* See Figure 4 b).
- W*ill the circle be larger or smaller than the one I just drew?* See Figure 4 c).



a) A circle drawn using a hole that is far from the fixed pivot



b) A second circle drawn using a hole closer to the fixed pivot   c) Comparing the two circles

Figure 4: Using a strip of pegboard as a compass, and then comparing circle sizes

<u>Science Notebooks</u>:

- Make a **diagram** showing the path of an output that is **far** from the fixed pivot.
- Make **another diagram** the path of an output that is near the fixed pivot.
- **Explain** what these diagrams tell you about how to fixed the Frustrated Butterfly Net**.**

4. **Fixing the Butterfly**: Ask students to use the information about circles to redesign their mechanisms, so the butterfly net catches the butterfly.

Outcomes

The conclusions of this lesson should be that:

- The further the fixed pivot is from the input link, the less the output will travel.
- Any link with a fixed pivot can be used to draw a circle. The further the pen is from the fixed pivot, the larger the circle will be.
- Moving the input link closer from the fixed pivot makes the output go further because it is part of a larger circle.

Assessment

Show students a pegboard Butterfly-model where the output doesn't travel far enough, because the floating pivot is too far from the fixed pivot, as in Figure 5. Ask:

- What could I do to fix this?
- Why does your solution work?

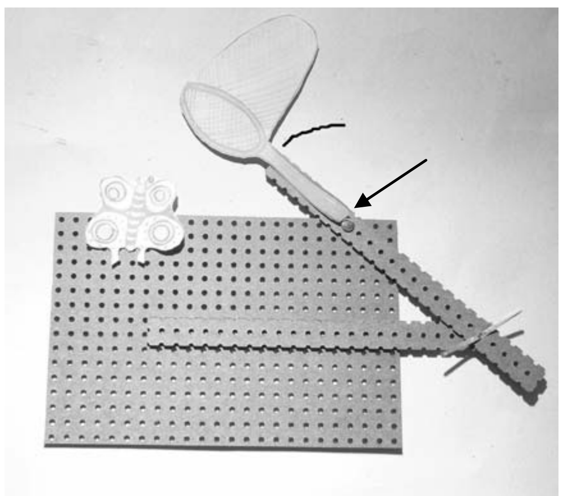


Figure 5: Butterfly net that travels too little, because fixed pivot (marked by arrow) is too high

Extensions

- Make a Windshield-wiper mechanism where one of the windshield wipers goes much further than the other.
- Make a Mouse-and cheese mechanism where the mouse and cheese miss each other.

Troubleshooting

Students may have difficulty tracing the output paths. One way to do this involves two people: one mover and one tracer. The mover's job is to hold the base steady with the right hand, and operate the input with the left hand. The tracer does the actual drawing of the paths using a pencil or marker to follow the path of the output from beginning to end. See Figure 6.

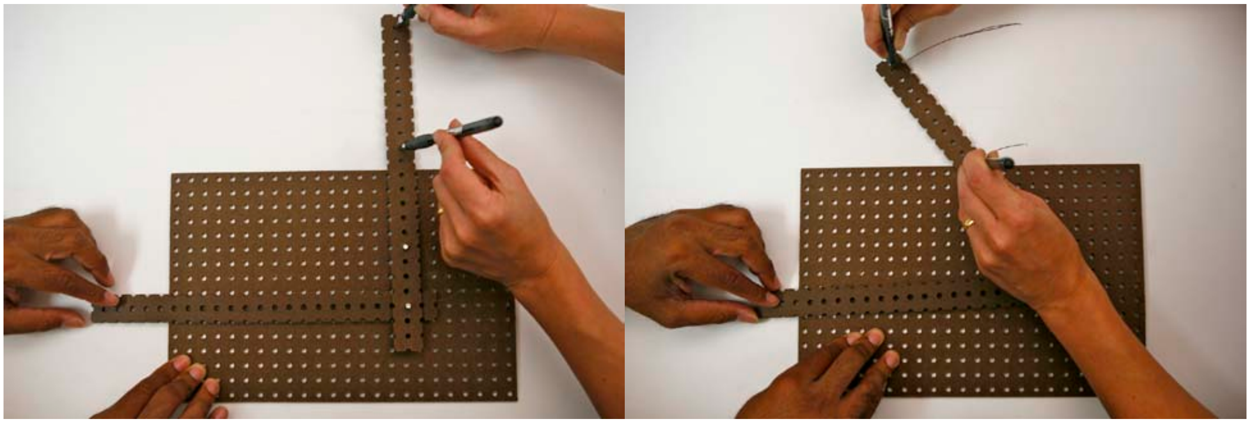


Figure 6: One person tracing two paths on a lever, while another is operating the input link

The tracing process is difficult enough that it will probably require a teacher demonstration for the entire class. Hold the mechanism against the blackboard or chart paper, and serve as the operator. Ask one student to do the tracing, so students can see how the job can be done by two people. Emphasize the need to hold the base steady and follow both paths completely, because otherwise the two paths will not be comparable – it will not be a **fair test**. See Lesson 10 for a mini-lesson on fair tests.

Technical Background

As an object is moving, it passes through many different points on its journey – in fact, an infinite number, because a point is infinitesimally small! It's hard to think about infinity, but fortunately, there is an easy way to describe all of the points the object has passed through. By mentally joining all the points together, you get a line or curve that connects all the points, like in the game, "Connect the Dots." In geometry, the line or curve that does this is called the **locus** of the points. For example, if you drop something while standing still, the locus will be a vertical line from where you dropped it to the floor.

In this lesson, students trace the **output path** of a lever, which is an example of a locus of points. Because the fixed pivot forces the lever to rotate, the output path must be part of a circle, whose center is at the fixed pivot – in other words, an **arc**. The Technical Background for Lesson 8 discusses arcs in detail.

The central question in the lesson is:

- ✂ What controls the length of the output path?

To answer this question, it is very helpful to identify and label not only the **output path**, but also the **output arm,** which is the distance from the fixed pivot to the output.

Figure 4 shows the paths the outputs of two mechanisms would follow if you could trace all the way around: a circle. In all of our mechanisms, the output can't travel all the way around a circle, but only part of the way, as in Figure 5.

A section of a circular path is called an **arc**. The length of a straight line is easy, but does it really make sense to talk about the "length of an arc?" In fact it does, because an arc is part of a circle. The distance all the way around a circle, the **circumference**, is twice the radius times pi, (or $2\pi r$, for short). In using this formula, the **radius** is distance from the center to any point on the circle, and pi, the Greek letter π, is a constant that is equal to about 3.14. An arc is just a fraction of the circumference, so the **arc length** can be found by taking that same fraction of $2\pi r$. A fraction of the circumference – in other words, part of the way around a circle – is called an **angle**. Figure 7 shows these quantities.

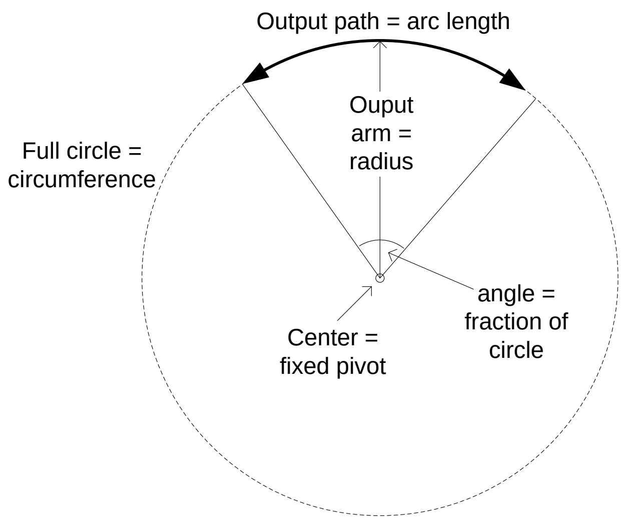


Figure 7: Circle relationships

The length of the output path (arc length) is proportional to the length of the output arm (radius). In other words, to make the path longer, use a larger radius. Figures 8 shows two output paths that have the same angle.

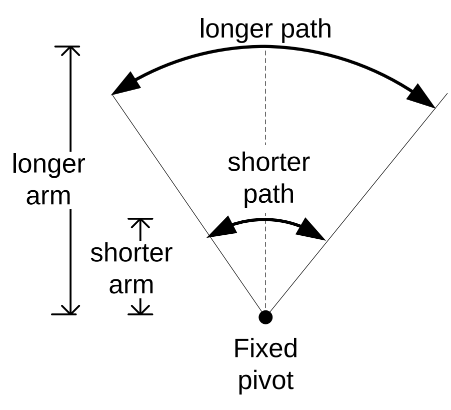
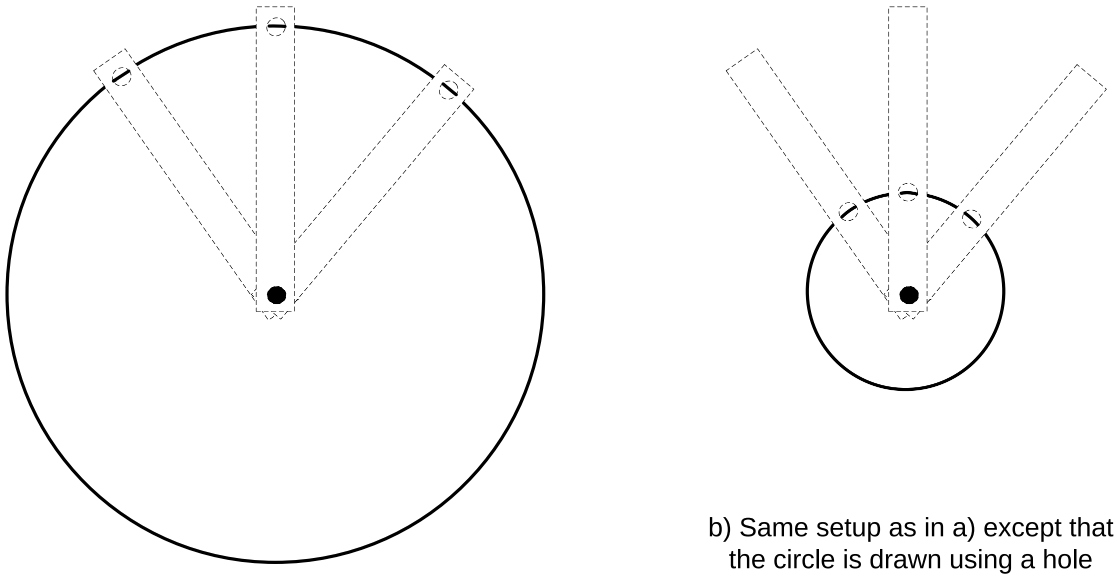


Figure 8: Comparing arc lengths and arm lengths

One output has a shorter arm than the other, and therefore a shorter path. These two arcs are parts of complete circles, such as the ones you drew as in Figure 4 (repeated below as Figure 9).



a) Circle drawn using hole far from fixed pivot

b) Same setup as in a) except that the circle is drawn using a hole nearer to fixed pivot

Figure 9: Circles drawn using different arm lengths

In each case, the center of the circle is at the fixed pivot. The radius of each circle is one of the arms. The longer output path is bigger than the input because its radius (arm) is longer. In fact, **ratio of arm lengths** is **equivalent to the ratio of path lengths** (output to input). When two ratios are equivalent, they are said to be **in proportion**.

The reason these two ratios are in proportion is that is that the ratio of circumferences of two circles is in proportion to the ratio of the two radii, according to the formula:

$C = 2\pi r$, which reads as "Circumference equals two times pi times radius."

An arc is only a fraction of a circle, so it might not seem obvious why the arc lengths, as well as the circumferences, should also be in proportion. They actually are, because but both input and output arcs have the same angle, which means their fractions of the circumference are the same. Therefore, the arc lengths are proportional to the arm lengths. If you double an arm length, the arc length doubles too. The terms and relationships are summarized in the Glossary.

Glossary

Angle: A number describing a fraction of any circle

Arc: Part of a circle

Arc length: Distance traveled in following an arc

Circumference: distance all the way around a circle

Center: When making a circle, this is the only point that doesn't move; one end of the radius is attached here

Locus of points: Line or curve that connects all the places that a point passes through

Output arm: Distance on a lever from fixed pivot (fulcrum) to output point; radius of input circle

Output circle: Circle centered at fixed pivot that output point could follow if it could rotate all the way around

Output path: Path actually followed by output point

Pi: Ratio between the circumference of a circle and twice the radius (also called **diameter**)

Proportion: Relationship between two ratios, which says that they are equivalent; for example, the ratios 2 to 1 and 6 to 3 are in proportion

Radius: Distance from the center to any point on a circle

Ratio: Relationship between two numbers, such as 2 to 1

Lesson 10: Controlling the amount of Force

Overview

This lesson begins with another MechAnimation problem: if the input link is made of cardboard, it can sometimes be hard to push, and may even fail to operate the MechAnimation, because the force required is more than the input link can withstand. In order to address this issue, students learn about force by experimenting with inputs at different distances from the fixed pivot.

Materials

- ✁ **Six Hammer MechAnimations –** one per group
- ✁ **Pegboard bases, strips and fasteners**
- ✁ **Template** for making Cutout figures of hammer and nail
- ✁ **Force Probes** made by printing Force Probe Templates onto Cardstock (at end of Procedure)
- ✁ **Science Notebooks**

Procedure

1. **Demonstration of MechAnimation and discussion of force requirements**. Conduct a whole-class meeting. Hold up the original Hammer MechAnimation. The original version has a heavy cardboard input link, which will not buckle when you operate it. Demonstrate how it works. Then replace the pegboard input link section by a piece of cardstock. See Figure 1, left.

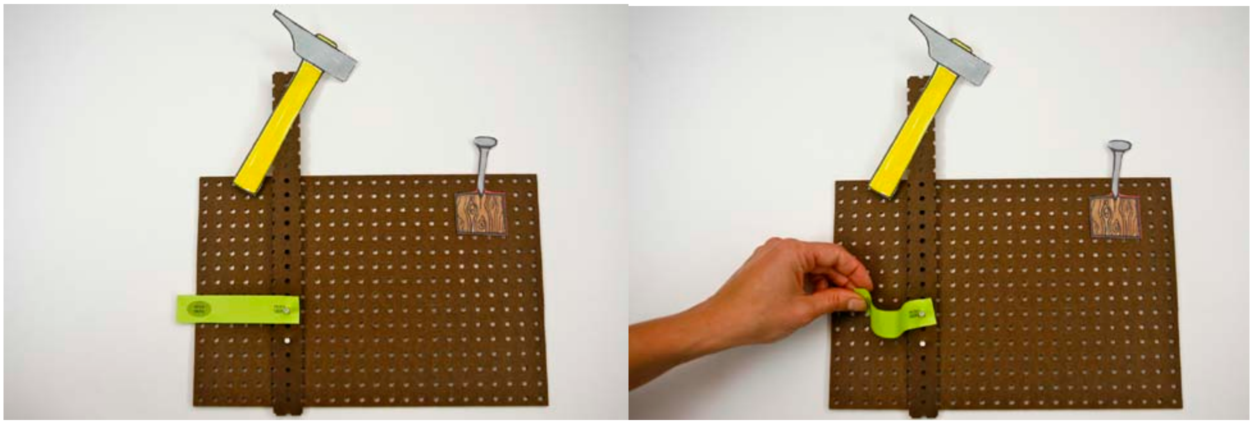


Figure 1: Hammer MechAnimation with thin cardstock section as input link

Science Notebooks
✁ **Predict** what will happen when your teacher tries to operate the Hammer.

Then demonstrate it, as in Figure 1, right, so everyone can see it buckle. Conduct a discussion about why the cardstock piece buckles, but the heavy cardboard doesn't, when used as part of the input link. To illustrate how buckling occurs when the force increases, have each student hold a piece of cardstock, and gradually push the two ends together until it buckles.

<u>Science Notebooks</u>
✂ **What did happen** when your teacher operated the <u>Hammer</u>?
✂ **How was it different** from what happened with the original <u>Hammer</u>?
✂ **Why** do you think the two work differently?

2. **Setting up the force experiment**. Introduce the concept of **force**: the amount of push or pull used to make something move. Explain that in the next experiment, they will be exploring how much force it takes to push an input that has to operate a <u>Hammer</u> MechAnimation.

   Provide pegboard materials, rivets and Hammer- and Nail-cutouts, and ask each student to make a <u>Hammer</u> using pegboard, rivets and cutouts. If necessary, review the directions of input and output motions, and locations of the fixed and floating pivots; see Lesson 6 and Figure 2. The numbers on the vertical strip (lever) should be facing up so you can read them, and the fixed pivot should go through the hole marked ZERO. See Figure 2.

Figure 2: Hammer made with pegboard and cutouts

   Distribute force probes, cut from the <u>Force Probe Template</u>, printed or photocopied onto cardstock. Instruct students to disconnect the floating pivot and remove the input link, and use a Force Probe instead of the input link. See Figure 3.

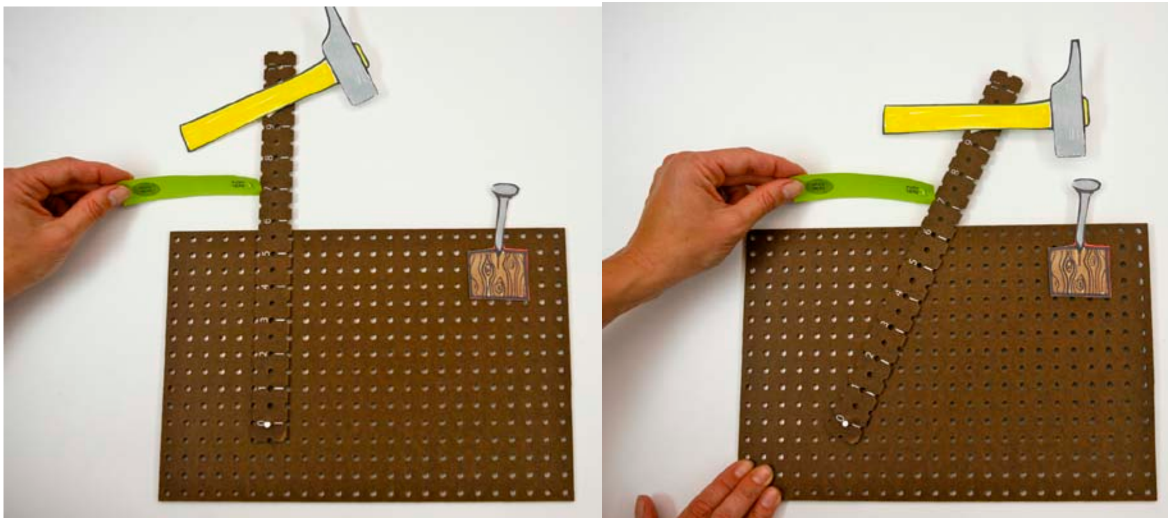


Figure 3: Hammer using Force Probe as input link

Demonstrate how to operating the hammer by using the force probe to push the lever.

3. **How does distance from the fixed pivot affect the amount of force needed**? Demonstrate how to perform the experiment. Each student uses a **force probe** to see how much force is needed at various points along the lever. The idea is to hold the cardstock strip at one end, between two fingers, and try to use it to push the pegboard strip against the rubber band, at various points along the pegboard strip. Points on the lever are marked by distance from the fixed pivot. Students should try the force probe at different marked distances, beginning near the far end, such as 7″, 5″, 3″ and 1″. If the force is too much, the force probe will **buckle**. Students should first try pushing the lever with the force probe at different points, just to get a sense of what before moving on to the next step. If it is too close to the fixed pivot, the probe will buckle, because too much force is required, as in Figure 4. It is far enough away, the probe will be able to operate the hammer, as in Figure 3.

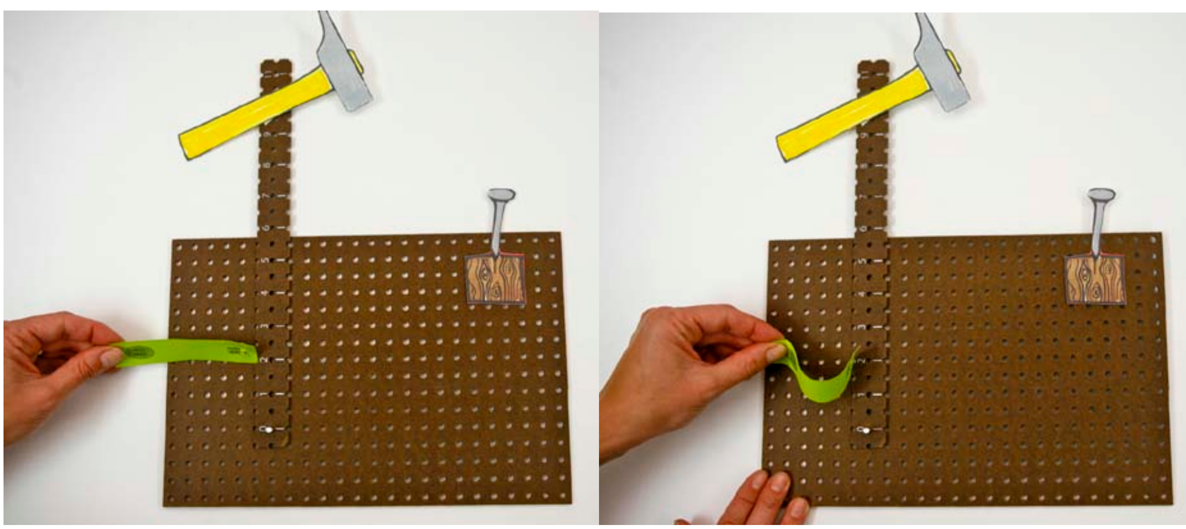


Figure 4: Sometimes the force probe can’t operate the hammer, because it buckles!

Mini-lesson on Fair Tests

The question in the experiment is:

✂ *How does the distance from the fixed pivot affect the way the force probe works?*

To conduct a fair test, you have to keeping everything else the same, except the variable you want to study – in this case the distance of the input from the fixed pivot. *If you change anything else, you won't be able to answer your question, because anything else you changed might affect the results*.

To illustrate this point, deliberately do the experiment incorrectly. For example, you might hold the force probe really close to the end while you push at 3 ″ from the fixed pivot (Figure 5, left), and far from the end when you push at 5 ″ (Figure 5, right). The force probe that is further from the fixed pivot seems to work *better* than the one that's closer, which is the opposite of what the experiment should show. The two force probe at 3 ″ holds more force *only because* it is held closer to the end. If both force probes were held the same way, the further one would be able to take more force.

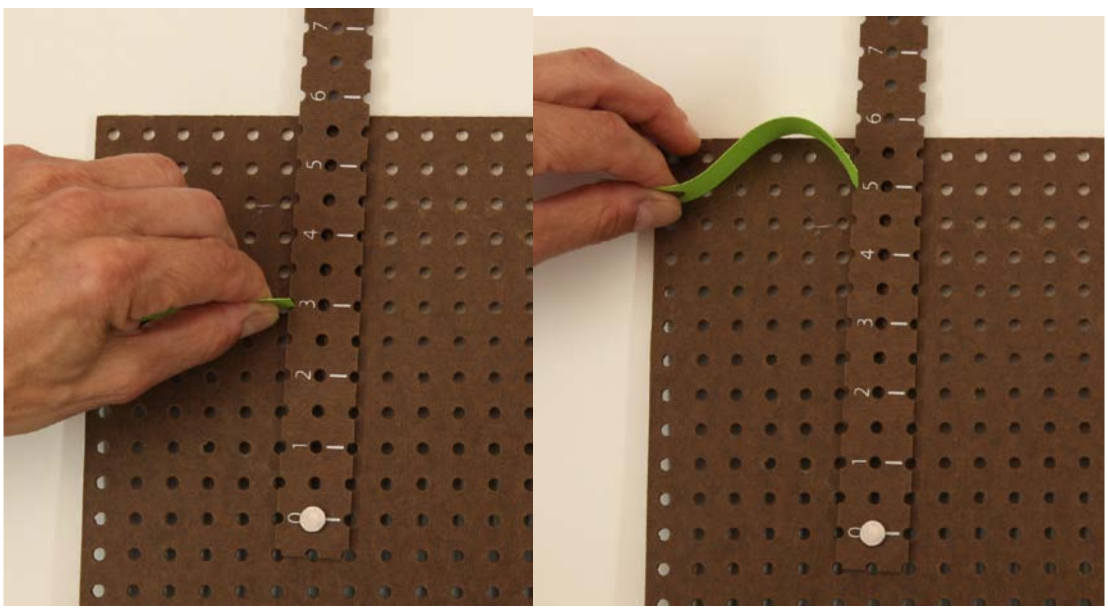


Figure 5: This is not a fair test, because the force probes are being held differently

Ask students:

✂ *What did I change between these two tests?*

✂ *What is wrong with this experiment?*

✂ *How could I change this to make it into a fair test?*

If this demonstration doesn't make the point clear, use a more drastic example of an uncontrolled variable, such as using a book instead one of the force probes.

4. **Conducting the experiment.** Once students have gotten an idea of how to do the experiment, they can collect data and enter it on the Worksheet. The force probes should be used the same way each time; remind students of the Mini-lesson on Fair Tests, if necessary. Students only need to use Row 1 of the Worksheet. (Row 2 is for the Extension activity.) In

Row 1, they should record what happens to the force probe at the distances marked 7″, 5″, 3″ and 1″, starting from the far end (longer input arm). Model this for students, by demonstrating how a force probe at a longer distance – such as 7″, is able to push the lever, while the same force probe at a shorter distance – such as 1″ – simply buckles, without affecting the lever at all. They should use their own language for describing what happens to the strip.

5. **Redesigning the Force Probe**. Pose this design challenge:

   ✁ *How could you redesign your force probes to withstand more force?*

   If students are not sure about how to do this, ask:

   ✁ *What could you do to make your force probe stronger?*

   The second and third items of the Worksheet provide space to describe two new redesigns of the force probe. Students should describe how they made each one, test it at each of the distances, 7″, 5″, 3″ and 1″, and record the results of each test in the tables.

Science Notebooks

✁ **Describe** how you did the experiment, including what you changed each time, and what you were trying to find out.

✁ **Explain** what happens to the force probe as you move it towards the fixed pivot.

✁ **Discuss** how the results of this experiment could help you design a better MechAnimation.

Outcomes

✁ Students should notice that the force probe tends to buckle more and more, as you move it closer to the fixed pivot. This indicates that the amount of force needed to move the lever is increasing too, as you move closer to the fixed pivot.

✁ You make a stronger force probe by doubling it, folding it or rolling it into a tube.

Assessment

✁ If the input to a lever buckles, what does that tell you about the amount of force needed to push the lever?

✁ How could you change the location of the input to reduce the amount of force? What effect would that have on the distance the output travels?

✁ If you want to keep the input in the same location, how could you change the input link to make it stronger?

Force probe Template

Directions: 1. Print or photocopy onto cardstock. 2. Cut along dashed lines to make 20 force probes

HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →
HOLD HERE — PUSH HERE →	HOLD HERE — PUSH HERE →

Name: ______________________ Date: ____________

Lesson 10 Worksheet

1. Use a standard Force Probe from the template to test the lever at 7", 5", 3" and 1" from the fixed pivot. Describe what happened at each distance.

Distance	7"	5"	3"	1"
What happened when you tried the standard force probe?				

2. Create a *new* Force Probe that you think will be stronger. Describe how you made it:

____

____

Name: ______________________ Date: ____________

Lesson 10 Worksheet, continued

Test your new Force Probe the same way you tested the standard one:

Distance	7"	5"	3"	1"
What happened when you tried the new force probe?				

3. Make a third Force Probe that you think will be even stronger. How did you make it?

____

Test your new Force Probe the same way you tested the other two:

Distance	7"	5"	3"	1"
What happened when you tried the third probe?				

Troubleshooting

As students do the experiment, they should notice that the force probe is easily able to push the lever at 7″, buckles slightly but is still effective at 5″, and becomes unusable at 3″ or 1″. Students are likely to use the word "bend" or "bent" rather than the more technically correct "buckle" or "buckled." This is not a serious issue. The distinction between bending and buckling is discussed in the Technical Background of Lesson 3.

It is important to start at the longer distance, and then work inwards, rather than the reverse, for two reasons:

1. By starting far away, they will initially be successful at moving the lever, so the buckling will present a real contrast.
2. After repeated buckling at a short distance, the force probe could become weakened, and no longer be effective even at 7″. You can always make more force probes from a new template, in case some get lost or worn out.

If students don't observe any buckling at all, even at short distances, they are probably compensating by holding the force probe closer to the lever. You may need to remind them that the goal of the experiment is not to make the lever move, but to investigate how much force it takes at different points. In order to conduct a **fair test**, they will need to hold the force probe where it says "HOLD HERE" each time they try it, as in Figures 3 & 4.

In the last step, students are asked to find ways to stiffen a force probe. If they are unsure about how to do so, here are some avenues they might want to pursue:

a. **Make it thicker.** Simply doubling the cardstock strip, by gluing or taping two identical pieces, will make it stiffer.

b. **Use a stiffer material.** Pegboard will not buckle, when used as a force probe. Not only is it thicker than the original cardstock force probe, but the Masonite™ used in pegboard is inherently stiffer than cardstock. Along similar lines, students might try taping stronger material, such as wood or plastic, as reinforcement to the cardstock.

c. **Use a different-shape rectangle.** The effective length of the rectangle runs from the point where it is held to the edge where it does the pushing; see Figure 6. By making the strip longer or shorter, or even just by holding it in a different place, students can increase or decrease its stiffness.

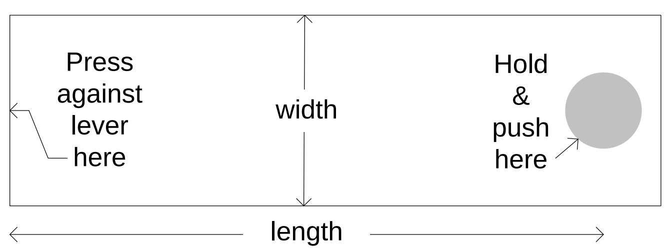


Figure 6: Height and length of the force probe

The width of the force probe has an effect too, but less so than the length. Students might want to try a wider or narrower strip. A very slender strip will have very little stiffness – it will be similar to a piece of string.

d. **Fold it.** A simple way to make a thicker force probe is to cut a double width, and then fold it so the fold line runs the long way, as in Figure 6. This probe is likely to be even stiffer than the glued double strip described in a., because the fold itself, as well as the V-shape, contribute additional stiffness (see Technical Background, below).

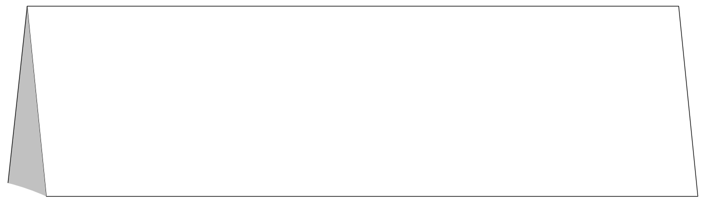


Figure 6: Strip folded the long way

Other kinds of folding are possible too: folding it the short way, pocket folds (Figure 7 a)) and zigzag folds (Figure 7 b)). Students could try each of these to see how stiff they are.

a)

b)

Figure 7: Multiple folds: a) pocket and b) zigzag

Technical Background

The experiment in this lesson illustrates quite a few important physical concepts. To make them easier to follow, we'll sort these ideas into three major categories: a) ideas about force and its effect; b) methods of increasing or decreasing stiffness; and c) relationships between force and distance.

a) How forces operate. In the experiment, students use one force to try to balance another. They push on the force probe, in an effort to counteract the friction force within the mechanism – which is mostly due to the rivet fitting tightly in the hole. Notice, however, that the arrangements and effects of these two forces are different. **Friction** tries to stop anything from moving. By contrast, the force probe is being pushed at one end, and resisted by friction at the other, which tries to make it shorter. That situation is called **compression**. The opposite of compression is **tension**, which tires to make something longer by pulling on it. The legs of a chair are in compression, while a stretched rubber band is in tension.

In the Technical Background section of Lesson 1, we developed the distinction between a **structure**, which has no moving parts, and a **mechanism**, which does have moving parts. Anything designed to support a force has to be a structure, because the parts of a mechanism will simply move when forces are applied. Both a rubber band and a chair are therefore examples of structures. When a rubber band snaps, or the legs of a chair give way, the structure has stopped supporting the forces that were applied. In this case the structure has experienced **failure**. When something is in tension, it gets longer and longer before it fails, which provides some warning. Compression failure, however, is different. For thin materials, such as paper or cardboard, the easiest way to get shorter is to **buckle**, which happens suddenly, and without warning. Buckling looks like **bending**, and the factors leading to them are similar, but they are actually quite different, for two major reasons:

- bending failure is gradual (like tension failure), while buckling is sudden; and
- the arrangement of forces is different; for details, see Figure 1 of Lesson 3.

b) **Making something stiffer.** Even though bending and buckling are different, the factors leading to them are similar. Resistance to either one is called **stiffness.** In the Extension activity, students can explore methods of increasing stiffness. Fundamentally, there are two solutions to this problem:

- **Use a stiffer material.** Some materials are obviously stiffer than others. Any property that varies when a different material is used, keeping everything else the same – such as forces, shapes and sizes – is called a **material property**. For example, wood, metal and even most plastics are considerably stiffer than rubber, as you can see by trying to stretch each one. **Stiffness** is an important material property to know about, when designing a structure. Another word for stiffness is **rigidity**. A force probe will be much stiffer when reinforced with wood or rigid plastic, as suggested in Troubleshooting, item c).
- **Use a stiffer shape.** The Troubleshooting section (items a), b) and d)) suggests ways to make a stiffer force probe, using the same material, cardstock. Making it thicker, wider, or folding it have the effect of increasing the stiffness. Making it longer (or holding it further out) has the opposite effect. Properties that vary due to a change of shape are called **shape properties**.

c) The Law of the Lever. The major point of this experiment is to develop a qualitative sense of the Law of the Lever, which was discovered by Archimedes in Ancient Greece:

- **To decrease the amount of force, increase the input arm (distance from input link to fixed pivot).**

For example, when a heavy kid is sitting on a see-saw, he can be balanced by a lighter kid sitting further out on the opposite side. The lighter kid exerts less force, due to gravity, but is located further from the fulcrum. See Figure 7.

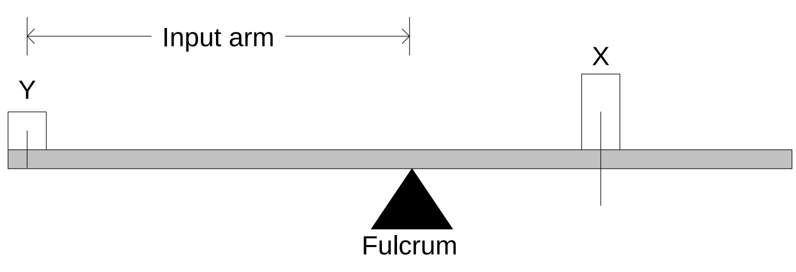


Fig. 7: Large weight X balances half the weight Y, because Y is twice as far away as X

In the experiment, the Law of the Lever is illustrated by the worksheet data, which shows that the chance of buckling is greater as the force probe moves closer to the fixed pivot. Buckling is an indicator of increasing force, and moving closer to the fixed pivot decreases the input arm. The Law of the Lever is the key to understanding many common objects. The handle of a nail clipper or nutcracker needs to be long, in order to reduce the force to a reasonable level, which most people can manage in their hands. Similarly, a bolt cutter would be useless if it had a short handle. Very few people would be able to exert the force needed to break a lock or chain, were it not for the Law of the Lever, which reduces the force needed by increasing the input arm.

Glossary

Compression: Configuration of forces that push towards each other from both ends, “trying” to make an object shorter

Controlled variable: Quantity that you don’t allow to change during the course of an experiment, in order to see the effect of the input variable only, which is necessary for a **fair test**.

Failure: Situation when an object can no longer resist the applied forces

Fair test: An experiment that controls all the variables except one – the input variable, whose effect you’re investigating.

Force: Amount of push or pull needed to start something moving or balance another force

Friction: A force that resists movement, because things are rubbing against each other.

Input arm: Distance on a lever from floating pivot (where input link is attached) to fixed pivot (fulcrum); radius of input circle

Input circle: Circle centered at fixed pivot that floating pivot could follow if it could rotate all the way around

Input variable: Quantity whose effect you want to investigate

Law of the lever: Statement that force needed to operate a lever increases as distance from the fulcrum (input arm) decreases, and vice versa

Material properties: Characteristics that change because of a substitution of materials, controlling all other variables, such as size, shape and applied forces

Shape Properties: Characteristics that change because of a change of shape, controlling all other variables, such as type of material and applied forces

Stiffness: Ability of a part to resist bending or buckling, depending on both material and shape properties

Tension: Configuration of forces that pull away from each other from both ends, “trying” to make an object longer

Lesson 11: Redesigning MechAnimations

Overview

Based on their work with force and distance in Lessons 9 & 10, students should now have some background for redesigning their MechAnimations from Lesson 8, or for designing new ones. These new designs should take account of how the locations of the pivots affect the distances moved by the outputs, or the forces required at the inputs. Trying to balance distance and force requirements provides an example of tradeoffs.

Materials

- **MechAnimations previously made** in Lesson 8
- **Pegboard bases, strips and fasteners** for modeling the mechanism of a MechAnimation
- **Cardstock –** 100 sheets
- **Corrugated cardboard**– 50 sheets (8 ½ x 11") and 200 strips (1 x 11")
- **Paper fasteners –** 2 boxes of 100 each
- **Markers, Post-Its™ & craft supplies** for decorating MechAnimations
- **Science notebooks**

Procedure

1. **Review the lessons learned about distance and force**. Have students use their Science Notebooks to help them recall these two major conclusions:

   - (Lesson 9) **To make the output move further, move the floating pivot towards the fixed pivot**.
   - (Lesson 10) **To make the input easier to move** (requiring less force), **move the floating pivot away from the fixed pivot.**

   Discuss whether it's possible to do both at the same time. If not, then you have to decide which is more important – an example of making **tradeoffs**.

2. **Review of design process**. Explain that students will be using these ideas, and anything else they have learned, to redesign their MechAnimations from Lesson 8 or make new ones. Students will present their finished products in the next lesson. Discuss how they could begin doing their design. Ask them what would help them think about it, and test their ideas before they actually make the final one. Help them remind themselves of the techniques they may have already used: writing about what they want it to do, describing inputs and outputs (Lessons 1 & 2), making diagrams (Lesson 5), keeping track of direction of motion (Lesson 6), combining mechanisms (Lesson 7), writing the story first, then modeling the mechanism in pegboard (Lesson 8), controlling distance (Lesson 9), reducing the amount of force (Lesson 10).

3. **Designing and redesigning MechAnimations**. Save most of the period for them to begin designing and then making new MechAnimations. Provide corrugated cardboard, in case students need it for making stiffer bases and strips. Ask:

   ✂ How is this material different from the pegboard and cardstock we have been using?

   ✂ What problems could we use it to solve?

   Suggest that they take their original MechAnimations apart, stiffen some of the pieces with corrugated cardboard, and then re-assemble them.

<u>Science Notebooks</u>

✂ Describe the MechAnimation you are trying to make. Identify the input, the outputs and draw a diagram showing how the input and outputs move.

✂ Explain how you used what you learned about force and distance to make your MechAnimation work.

✂ Describe any problems that you had, including things that didn't work the way you wanted them to.

4. **Class discussion of issues:** Toward the end of the period, convene a whole-class meeting to discuss issues that came up. This should be more than a sharing session! Ask selected students to present their work-in-progress. The class has to guess what it represents and how it will move when the input is operated. The class should discuss the issues that came up, and how both the presenter and others have tried to address similar issues. This discussion should provide genuine assistance to students, because many of the issues are likely to be similar.

Outcomes

Students should be able to describe their design process, including how they dealt with the tradeoff between increasing the distance traveled, and reducing the amount of force needed.

Assessment

✂ If your output doesn't move as far as you want, what could you do?

✂ If your input buckles when you try to operate it, what should you do?

✂ If you want <u>both</u> a large output movement and no buckling, how could you solve <u>both</u> problems?

Troubleshooting

The results from Lessons 9 and 10 are summarized in the Procedure as follows:

✂ **To make the output move further, decrease the input arm** (distance from the fixed pivot to the input link and its floating pivot).

✂ **To make the input easier to move** (requiring less force), **increase the input arm** (distance from the fixed pivot to the input link and its floating pivot).

These requirements are in conflict, because you can't make the input arm *both* longer *and* shorter at the same time! Therefore you have to choose between making the output move further, and reducing the force needed at the input. In fact, this dilemma is inherent in the Law of the Lever, which says that there you can only reduce the force by increasing the distance traveled, and vice versa. In engineering, it happens frequently that two desirable outcomes are not consistent with each other. You have to decide between one and the other, a process we have called **making tradeoffs** (see Technical Background and Glossary for Lesson 7.)

However, in this case, there is a way out, suggested by the Extension activity to Lesson 10. You could use a stiffer piece of material for your input link, and thereby achieve both maximum movement, while at the same time avoiding buckling. Alternatively, corrugated cardboard is much stiffer than cardstock, so it could be used to replace cardstock links, where buckling is an issue.

Lesson 12: Presenting MechAnimations

Overview

Students complete and test the MechAnimations they began in the previous lesson. The lesson provides a variety of options for making interdisciplinary connections, presenting them to the class, the school and the school community.

Materials

- Students' MechAnimations from Lessons 8 & 11.
- Manufactured mechanisms from Lesson 1 (see Assessment)

Procedure

1. **Completing MechAnimations**. Students finish making their MechAnimations, and test them to see if they work as they are supposed to. This might also be an opportunity to develop connections with other subject areas:

- **Art**: Decorate your MechAnimation, as an Art project.
- **Social Studies**: Create a MechAnimation that illustrates a historical event, such as the Boston Tea Party.
- **Science**: Create a MechAnimation that illustrates a science concept, such as lifting something against gravity.
- **Literacy**: Build a story around your MechAnimation.

2. **Presenting MechAnimations.** Here are several suggestions for culminating events, providing opportunities for students to present their designs:

- **Bulletin board or poster display**: MechAnimations can be attached to poster boards or bulletin boards. By using push pins strategically – for example, at the corners – you can avoid interfering with the mechanism, allowing viewers to try them out to see how they work. If students have written stories or made diagrams, these can be posted too, as part of the same display.
- **Museum table**: For Parent-teacher Conferences, Open School Night, or other community events, the MechAnimations can be displayed loose on tables with signs inviting viewers to guess what they will do and then test them.
- **Invention Convention:** Stage a science-fair style event, to give students an opportunity to explain what they made and how it works to parents and other visitors.
- **Puppet show:** You could coordinate all of the MechAnimations around a common theme, and use them for staging a class puppet show.

Assessment

Here is a technique for assessing the entire unit. Provide each student with a choice of any of the manufactured mechanisms from Lesson 1. Ask them to:

- ✁ Make a sketch of the mechanism.
- ✁ On the sketch, label the input, output and each pivot.
- ✁ Observe how the mechanism was designed:
    - What is each part made of?
    - Where did they put the pivots?
    - What did they do to make it easier to use?
- ✁ What have you learned from this unit that helps you to understand this mechanism?