# Force & Motion 4-5: ArithMachines

Physical Science Comes Alive: Exploring Things that Go
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## Introduction

### Overview

In ***ArithMachines*** students develop their understanding of force and motion. As students solve the challenges presented in these lessons they discover how levers and lever systems work. They learn about the ratio of inputs to outputs, both in terms of the distances they move, and in terms of the forces involved. Students experience the proportional relationships that govern forces and distances in lever systems. MechAnimations are home-made kinetic toys, which depict animals, people or scenes with movable parts. Students apply what they have learned as they design and construct their own MechAnimations.

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## *Background*

The best way to prepare for teaching this unit is to try the activities for yourself. Begin by playing with the pegboard bases and strips. Connect them in different ways using rivets and paper fasteners. Next try the challenges presented in Lessons 3 and 4:

✁ *Make a mechanism using two strips so that one strip controls the other*.

✁ *Make a pegboard mechanism where one input drives two or more outputs*

Try the Worksheets that accompany Lessons 3 and 4. If you are unsure about how to respond, construct the mechanism that is shown in the worksheet to see how it works.

Knowledge of how mechanisms work is put to use in creating MechAnimations. 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. You can see examples of student MechAnimations are on the City Technology website at http://www.citytechnology.org/node/7. MechAnimations by project staff are at http://www.citytechnology.org/stuff-that-works/design_puppets07.html.

This is an interdisciplinary unit. The mathematics of ratios and proportions is learned through mechanisms. MechAnimations integrate science and art and motivate story writing and telling. Most of all, this is a unit students enjoy. We hope you enjoy it with them.

## *Guide to the Lessons*

This unit is subdivided into 12 lessons and two extension 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.

**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.

## Table 1: Materials needed for ArithMachines (per class of 30)

| Item | Lesson # | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Ext 1** | **Ext 2** | |
| **Materials for Constructing Mechanisms** | | | | | | | | | | | | | | | |
| Pegboard Bases 8″ x 12″ | 30 | 15 | 30 | 30 | 30 | 30 | 15 | 15 | 15 | 30 | 30 | | 15 | 15 | 30* |
| Pegboard Links 1″ x 12″ | 60 | | 60 | 120 | 120 | 90 | 120 | 30 | 45 | 120 | 120 | | 15 | | 120* |
| Pegboard Links, numbered | | 15 | | | | | 45 | 45 | 15 | 15 | 30 | | 15 | | 60* |
| 10’ rope | | 1 | | | | | | | | | | | | | 1* |
| 8-32 screws, flat nuts & wing nuts | | | | | | | | | | | | | 15 | | 15* |
| Stands for base | | | | | | | | | | | | | 15 | | 15** |
| Stands for links | | | | | | | | | | | | | 15 | | 15* |
| Rivets 3/16 ″ diam . x 5/8 ″ | 60 | 45 | 60 | 180 | 180 | 120 | 30 | 30 | 15 | 180 | 180 | | 15 | | 200* |
| Brass fasteners (box of 100) | 1 | | 1 | 2 | 2 | | | | | 2 | 2 | | | | 5 |
| Cardstock , assorted colors | | | | | | | | | | 200 | 200 | | | | 400 |
| Cardboard 8” X 12” | | | | | | | | | | 60 | 15 | | | | 75 |
| Cardboard 1” X 12” | | | | | | | | | | 250 | 50 | | | | 300 |
| Rubber bands (#16) | | | | | | | | | | | | | 40 | | 40* |
| Paperclips, jumbo | | | | | | | | | | | | | 400 | | 400* |
| Assorted mechanisms | | | | | | | | | | | 5 | | | 5 | 5* |
| Masking tape (rolls) | | | | | | | 1 | 1 | | 4 | 4 | | 1 | | 4 |
| **Sample Mechanimation** | | | | | | | | | | | | | | | |
| Whale Chasing a Boat | | | | | 1 | 1 | | | | | | | | | 1* |
| **Templates, printed on Cardstock** | | | | | | | | | | | | | | | |
| Arc Measures: punched | | 35 | | | | | | | | | | | | | 30 |
| Force Probes | | | | | | | | | 15 | | | | | | 30 |
| MechAnimation pictures, assorted | | | | | | | | | | 40 | | | | | 30 |
| **School supplies** | | | | | | | | | | | | | | | |
| Rulers in mm. | | | | | | | | | | | | | | 15 | 15* |
| Chart paper sheets | | | | 2 | | | 6 | 6 | 2 | | | | 4 | 4 | 24 |
| Markers, crayons -class set | | | | | | | | | | 1 | 1 | | | | 1 |
| Package of Post-its™ | | | | | 1 | 1 | 1 | | | 1 | | | 1 | | 5 |
| Scissors (assorted) | | | | | | | | | | | | | | 16 | 16* |
| Scissors for cutting | | | | | | | | | | 30 | 30 | | | | 30* |

* Reusable items

# Lesson 1: 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)
- Two types of **Fasteners**: rivets 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 (three each of rivets and paper fasteners). Encourage students to build whatever they can with these materials. If necessary, demonstrate how to join pegboard pieces using the rivet and paper fastener and how to remove the rivets (see http://www.citytechnology.org/node/1622 ). 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?

| **Science Notebooks** |
|---|
| - 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?*

   Introduce the word **pivot** to describe a fastener around which a part of a mechanism can turn.

### *Outcomes*

In the course of this lesson, students should:

✁ gain skill in assembling the parts of structures and mechanisms;

✁ learn to distinguish between mechanisms and structures; and

✁ be able to convert one into the other.

They should develop the following understandings:

✁ A structure has no moving parts.

✁ A mechanism does have moving parts.

✁ To convert a structure into a mechanism, you always have to remove fasteners.

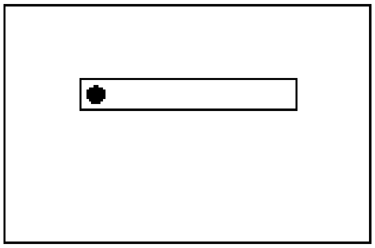
✁ To turn a mechanism into a structure, you have to add fasteners.

Name: ______________________________ Date: __________________

# Structure or Mechanism?

Label the Structures "S' and the Mechanisms "M"

a)



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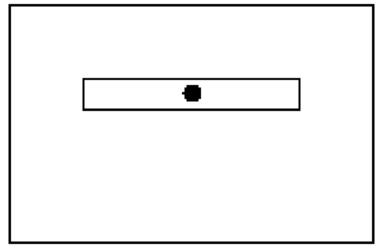

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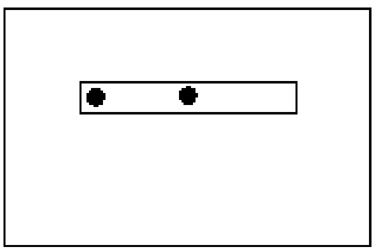

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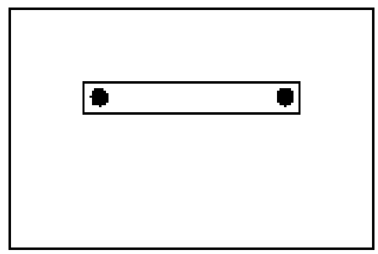

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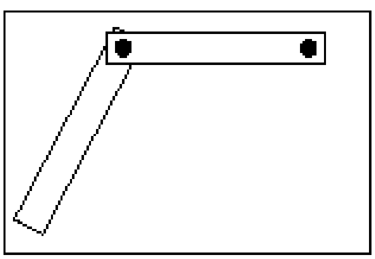

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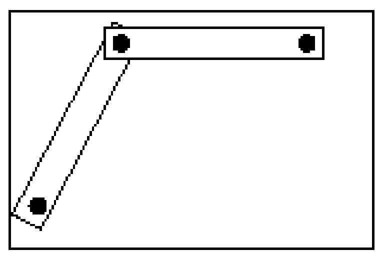

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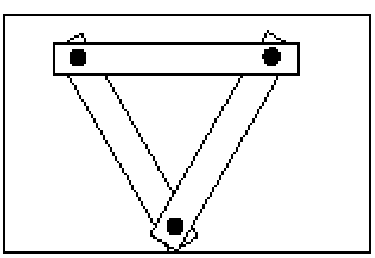

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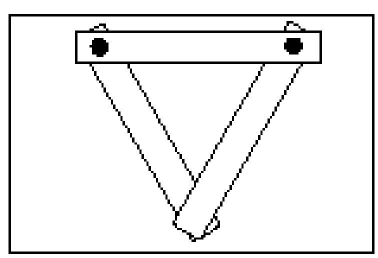


# Lesson 2: Moving around a pivot

## Overview

Students investigate movement around a pivot. What path is followed? How does the length of the path change with its distance from the pivot?

## Materials

- One **10′ rope** with markers at 5′ and 10′.
- Pegboard **bases and strips** (one per student) and three rivets per student.
- **Paper** to place on the base for tracing input movement.
- **Science Notebooks**

## Procedure

1. **Introduce the concept of path**: Demonstrate a pegboard base with the 0” hole of the strip connected to the bottom of the base. The strip is a lever and the connection to the base is a fixed pivot. It is a pivot because it allows the lever to turn around it. It is a fixed pivot because it attaches the lever to the base. Place a marker at the end of the lever and move the lever from one side of the base to the other. Discuss the shape of the path that is followed by the marker. Introduce the term “arc” to describe this path. Later in the lesson students will see that this arc is part of a circle. Ask*:*

   - *How could you know how far the marker goes*?

2. **Paths with a rope**: Clear a corner of the classroom (or go on the playground). One student, the fixed pivot, holds the end of the rope tight to his waist while standing against the front wall. A second student holds the rope at the 5′ point and a third holds the rope at the 10′ point. Keeping the rope straight and taut, challenge the two students at the 5′ and 10′ points to walk in a straight line to the back of the room.

   - *Could you walk in a straight line to the back of the room?*
   - *What shape of path did each student follow?*
   - *Who had the longest path? How do you know?*

   Let two more students hold the rope at the 5′ and the 10′ marks. This time let the class suggest how to measure how far each one goes. Again, be sure the rope is taught and straight.

   - *Who had the longest path? How do you know?*
   - *How far did the student at 5′ go? How far did the student at 10′ go?*
   - *Why do you think the student at 5′ had a shorter distance than the one at 10′ ?*

   All students should have the experience of being prevented from going in a straight line. This provides a kinesthetic grounding for seeing how a link also moves in an arc around a pivot.

Students may suggest that a fair test of the lengths of the paths at the 10′ marker and the 5′ marker requires that the same student count steps at each location. If so, this is a good experiment to do. You can collect data on the number of steps taken at the 5′ and 10′ markers by different students, and comparing results.

3. **Setting-up the pegboard for tracing paths of inputs**: Provide each student with a base, two numbered strips, six rivets, and pre-punched paper on which to trace input paths.

   Directions:

   a) Place the base in portrait position.

   b) Place two rivets up through the base, four holes from the top, one on either side of the base. These will function as stops.

   c) Place one rivet in the bottom row of holes, eight holes from the left side.

   d) Place the pre-punched paper over these three rivets. You may see a video of these instructions at http://citytechnology.org/node/1644.

   e) Place the 0″ hole of the link over the hole at the bottom of the base.

   Tell students that this link is a **lever**. Whatever pushes the lever is the **input**.

4. **Tracing input paths**. Directions for the experiment are below. You may also see a video of tracing input paths at http://citytechnology.org/node/1645.

   a) Place a pen in the notch next to the 2″ position of the lever, and trace the 2″ path as the output is pushed from the left hand stop to the right hand stop.

   b) Repeat #1 with the pen at the 4″ position and the 8″ position of the lever.

   c) Measure the length of each path and write it next to the path you drew.

   d) Complete Lesson 2 Worksheet: Motion around a Pivot.

**Science Notebooks**

✂ Place your tracing of the input paths at 2”, 4” and 8” from the pivot in your science notebook.

✂ Complete Lesson 2 Worksheet and place it in your science notebook.

5. **Whole-class meeting and discussion**: Encourage children to discuss what is ***similar*** between the rope experiment and the tracings on the pegboard. In the experiments

   a) the paths followed by the students and the input link (or floating pivot) are arcs,

   b) the further the student or input link is from the fixed pivot, the longer the path.

   Discuss the path followed by the input to the lever if the stops are removed.

   ✂ *What path would you follow if you were at the end a rope, if there were nothing to stop your movement, except for a person holding the other end?*

## *Outcomes*

In the course of this lesson, students should learn that

- ✂ The path of a point (or input) moving around a (fixed) pivot is an **arc**.
- ✂ An arc is a piece of a circle
- ✂ The further the input is from the (fixed) pivot, the longer is the path of the input, or arc.

← Stop

Stop →

Template for
# Motion around a Pivot

Directions:
1. Punch black holes for two stops and one fixed pivot.
2. Insert rivets in pegboard and place template over them.
3. Attach link to fixed pivot at 0" hole.
4. Trace paths in both directions from X's at 2", 4" and 8" holes

Trace at 8 " ← X → Trace at 8 "

Trace at 4 " ← X → Trace at 4 "

Trace at 2 " ← X → Trace at 2 "

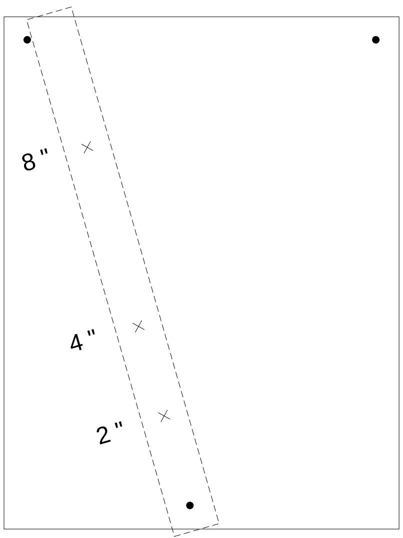


Fixed pivot →

Name: ____________________ Date:_______________

## Lesson 2 Worksheet: Motion around a Pivot

Draw in the three paths you traced on the template:




How are the three paths similar? ___________________________

___________________________

How are the three paths different? __________________

___________________________

What is the shape of each path?

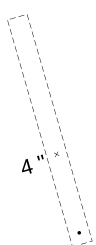
___________________________

What happens to the path as you move away from the fixed pivot?

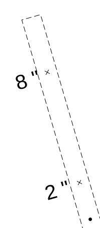
___________________________

Suppose the stops were removed, and the base was really big.

Draw the path the 4" hole would follow if there were no stops




Draw the path the 2" & 8" holes would follow if there were no stops




How are these paths different from the ones drawn with the stops?

_______________________________________________________

How do these paths change as you get closer to the fixed pivot?

_______________________________________________________

# 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 invent a new way to use a fastener. They observe the directions that each strip moves towards.

## *Materials*

- Pegboard bases, strips and fasteners (as in Lesson 1)
- Science notebooks

## *Procedure*

1. **Introduction to the materials and the activity:** Demonstrate (a) a base with a strip connected to it by two fasteners and (b) a base with a strip connected to it by one fastener. Review from Lesson 1 what makes (a) a structure and (b) a mechanism. Review how the structure can be converted to a mechanism and the mechanism to a structure.
2. **Design Challenge**: Present today's task:

   - **Make a mechanism using two strips so that one strip controls the other**.

   One strip controls another when it makes the other strip move back and forth.
3. **Analyzing mechanisms**: As students are working, analyze their work and pose questions such as these:

   - If one of the strips is fastened with two fasteners so it doesn't move: *How can I change this strip so it can move*?
   - *Show me how one piece (*the input*) makes another one (*the lever*) move.*
   - *Does the input move in the same direction as the end of the lever?*
   - *Can you change this so the input will make the lever go in the opposite direction?*

   Note which students have made mechanisms where the input moves in the same direction as the end of the lever (a 3$^{rd}$ class lever) and which have made mechanisms where the end of the lever (the output) moves in the opposite direction from the input, making it a 1$^{st}$ class lever.

   | **Science Notebooks** |
   |---|
   | - Make a diagram of your mechanism. |
   | - Describe how it works. |
   | - After the class discussion, label the input and output of your mechanism. |

4. **Whole-class discussion and sharing**: Introduce the terms **input** and **output**. Ask students to describe their mechanisms by identifying the input, and describing the way it controls the

output. As they operate the mechanism, focus their attention on the directions of movement of the input and output.

✂ *Describe your mechanism using the words "input", "control" and "output."*

✂ *Do the input and output go in the same directions, or do they go in opposite directions?*

Emphasize the idea that the input **controls** the output.

5. **Two types of pivot**: After a few presentations in which students identify inputs and outputs, introduce two more terms: a **fixed pivot,** which connects a strip to the base, and a **floating pivot**, which connects one strip to another. Ask students to identify fixed and floating pivots, as they describe their mechanisms.

6. **Directions of movement and locations of pivots**: Ask students with mechanisms whose <u>inputs and outputs go in the same directions:</u>

✂ *Is the **floating pivot** between the fixed pivot and the output?* Or,

✂ *Is the **fixed pivot** between the floating pivot (the input) and the output*

Introduce the term **3rd class lever** to describe a mechanism whose output and input go in the same direction, and whose floating pivot is between the fixed pivot and output.

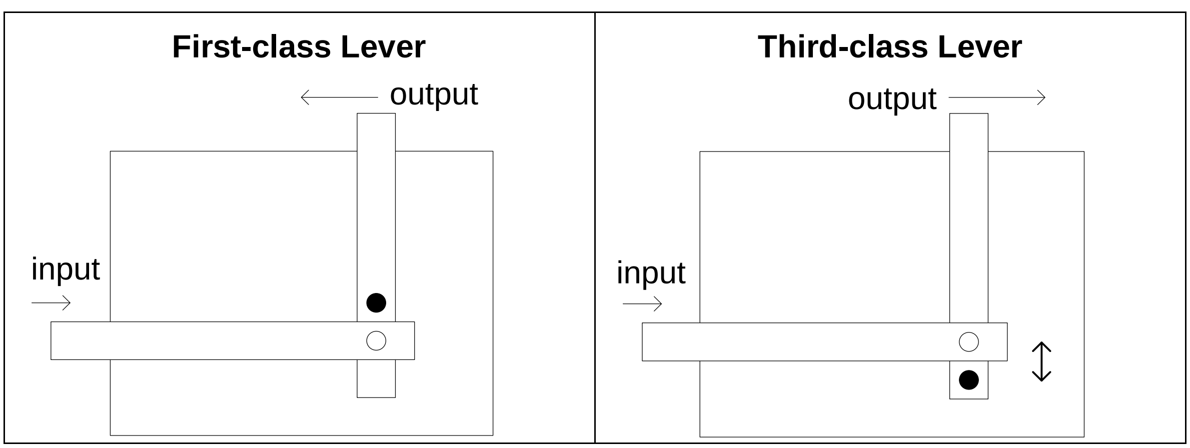
Ask students with mechanisms where the output goes <u>in the opposite direction as the input</u>:

✂ *Is the **floating pivot** (the input) between the fixed pivot and the output?* Or

✂ *Is the **fixed pivot** between the floating pivot (the input) and the output*

Introduce the term **1st class lever** to describe a mechanism whose output and input go in opposite directions. The fixed pivot of 1st class lever lies between the floating pivot and the output.

It is important to distinguish between the two kinds of pivot, so a different symbol should be used for each one. The diagram below uses a solid circle for a fixed pivot and an open circle for a floating pivot.




Key: ○ Fixed pivot (attaches strip to base)
○ Floating pivot (attaches strip to strip)

**Science Notebooks**

✁ Label the input and output of each mechanism you have drawn.

✁ Use arrows to show the directions of each input and each output

✁ Use the symbols for fixed and floating pivots.

**Homework:** Complete the Worksheet: Which Way will it Move?

**Extension:** Circle the 1st class levers on the Worksheet.

## *Outcomes*

In this lesson, students develop skill in making mechanisms in which where one strip (the input) controls the movement of a second strip (the lever). The output of the mechanism is located on the lever. In the course of this work they should learn that:

- ✁ to make one strip control another, you a fastener that connects one strip to another, but not to the base;
- ✁ there are two basic kinds of pivots: one that is fixed to the base, and another that is able to "float," or move freely above the base;
- ✁ every mechanism has an input – the part you operate – and an output – the part that moves as a result of moving the input;
- ✁ the input and the output go in the same direction when the floating pivot is between the fixed pivot and the output; and
- ✁ the input and the output go in opposite directions when the fixed pivot is between the input and the output.

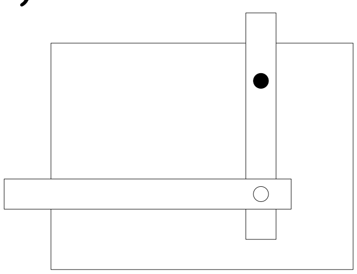
Name: ____________________ Date: ___________________________

# Lesson 3 Worksheet: Which Way will it Move?

1. Write “input” next to the input link
2. Draw an arrow to show the direction of the input.
3. Draw another arrow to show the direction of the output.

Key:
- Fixed pivot (attaches strip to base)
- Floating pivot (attaches strip to strip)

1)



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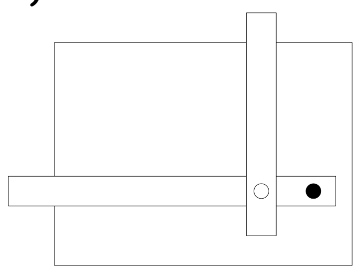

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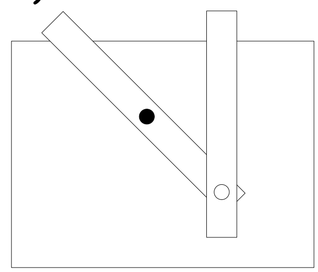

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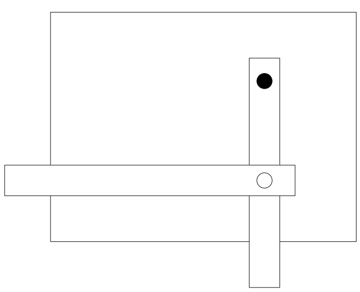

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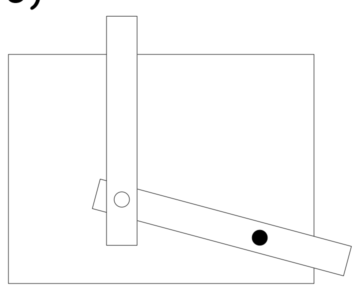

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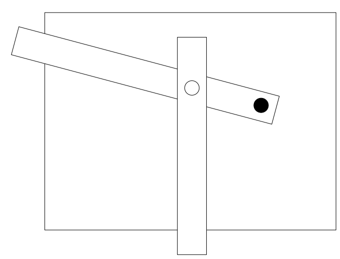

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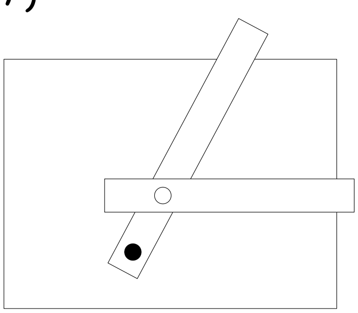

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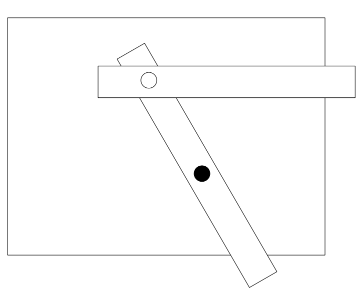

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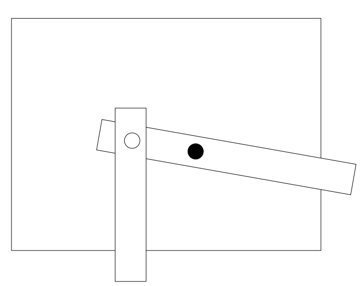


# Lesson 4: Combining mechanisms

## Overview

Students combine two mechanisms that are similar to ones they made in Lesson 3. In doing so, they invent mechanisms with one input that controls two outputs, and see how even more outputs can be added. These mechanisms are the starting points for creating cardboard figures that are mechanically animated to tell a story. We call these figures **MechAnimations**.

## Materials

- Three **pegboard mechanisms**: **X** and **Y** each has one input and one output, like the mechanisms students have already made in Lesson 3. The third mechanism combines X and Y into a single mechanism with one input and two outputs. Suggestions for making the three mechanisms are available at http://citytechnology.org/node/1691.
- **Large drawing** of a mechanism with one input and one output.
- **Pegboard base, four links and six pivots** per student.

## Procedure

1. **Demonstrate the movement of two pegboard mechanisms,** each with one input and one output. Introduce the idea that two mechanisms can be combined into one. Lay one mechanism on the other so that one input lies over the other. Grasp the two inputs together and demonstrate both mechanisms with your hand providing input to both mechanisms.
2. **Demonstrate a pegboard mechanism with one input and two outputs** that is a combination of the two previously demonstrated. Ask:
   - *How is it similar to a mechanism you have already made?*
   - *How is it different?*
   - *Where are the input and outputs?*

   Then present a large drawing of a mechanism with one input and one output. This video shows one way to do this. http://citytechnology.org/node/881. Ask:
   - *How would I need to change this drawing so it would show a mechanism with two outputs?*
   - *Could I add a third output? How would I show that?*
3. **Design Challenge**: Present this challenge to the class:
   - **Make a pegboard mechanism where one input drives two or more outputs**

   If students are not sure what to do, help them with prompts like these:
   - *Can you make a mechanism like you did where one strip controls another strip?*
   - *Where would you place another link to add a second output?*

✁ *How will you connect the second output to the input?*

✁ *Does the second output need any other fastener?*

**Science Notebooks**

✁ Make a diagram of the mechanism you made. Make the diagram clear enough that someone else could use it to reconstruct the mechanism.

✁ Place arrows on your diagram to show how the input makes the outputs move.

✁ Explain in words how your mechanism works.

4. **Preparing for making MechAnimations:** Select a few students to present the mechanisms they have made. Before the students operate their mechanisms, ask others to predict how the parts will move. Be specific, pointing to particular parts of the mechanism and asking in which direction that part will move, and why.

   Place Post-its™ on the outputs of a mechanism with two or more outputs. Then ask:

   ✁ *Invent a story you could tell with this mechanism.*

   ✁ *What pictures might you put on the post-its and on the board?*

   Save two of the mechanisms for use in Lesson 5.

**Homework**: Ask students to complete the Worksheet: What will Each Output Do?

**Extensions:** For students who finish quickly, provide more specific design challenges. For example, you could ask them to make mechanisms with:

✁ Two outputs that move in the same direction.

✁ Two outputs that move in opposite directions.

✁ One output that moves further than the other output.

✁ Outputs on two adjacent sides of the base.

✁ Outputs on opposite sides of the base.

✁ More than two outputs.

## *Outcomes*

✁ Each student should be able to construct a pegboard mechanism with one input and two outputs.

✁ Each student should be able to make a diagram of the mechanism, using different symbols for the fixed and floating pivots, and indicating the directions of movement of its parts.

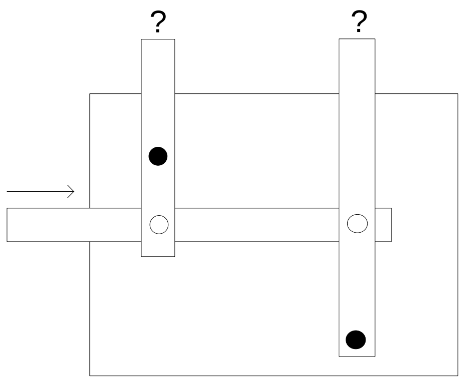
✁ Students should be able to predict the direction of movement of the outputs of a mechanism that they haven't operated yet.

**Name: _________________________ Date: ______________**

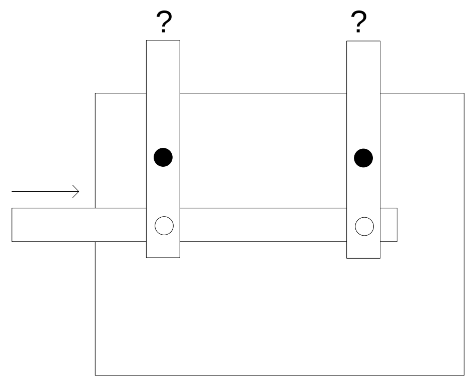
# Lesson 4 Worksheet: What will Each Output Do?

Use an arrow to show how each output will move when the input moves to the right.

NOTE: Each output is marked by a "?"




a)

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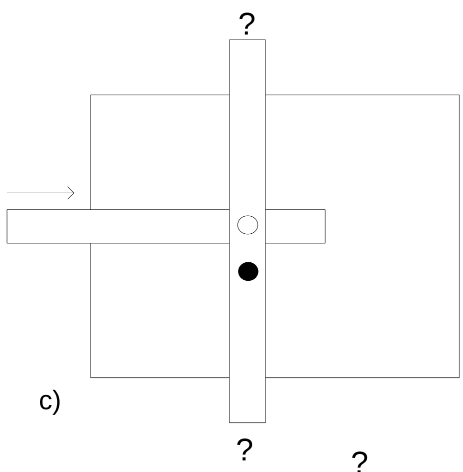


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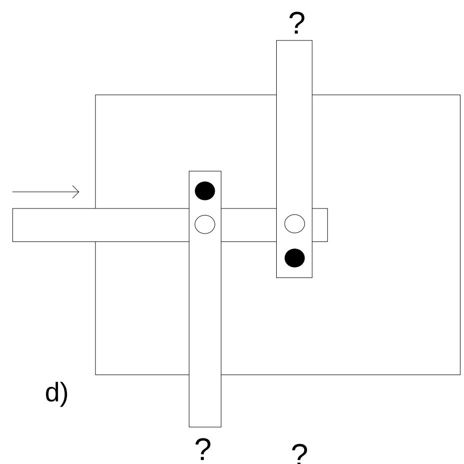
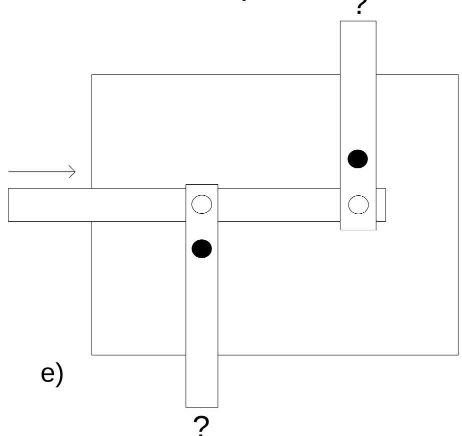
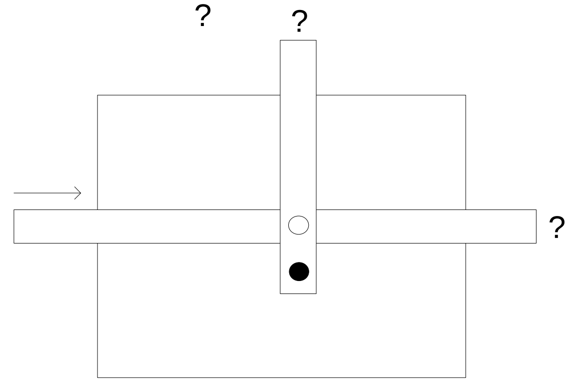



d)




e)




f)

# Lesson 5: MechAnimations I

## *Overview*

In Lesson 4, students made pegboard mechanisms with multiple outputs. Such a mechanism is the basis for a MechAnimation, a cardboard construction that uses a mechanism to tell a story. In Lesson 5 students devise stories that can be told through a MechAnimation, and they redesign mechanisms to go with the stories. This is the first of three lessons in which students create MechAnimations. It is continued in Lessons 10 and 11. In between are lessons through which students learn how to make their mechanisms move the way they want them to.

## *Materials:*

✁ **Pegboard mechanisms made by students** in Lesson 4

✁ Pegboard **bases**, **links** and **pivots** as in Lesson 4

✁ **Post-its ™** for demonstrating what the outputs can do

✁ Sample **MechAnimation:** " Whale Chasing a Boat"

## *Procedure*

1. **Class Discussion of MechAnimations**: Introduce the Whale Chasing a Boat MechAnimation. What story does this MechAnimation tell? Explain that there is a mechanism inside it that makes the MechAnimation move. Now demonstrate pegboard mechanisms made by students in Lesson 4. Brainstorm with the students what might be added to the outputs to make the mechanism illustrate a story. Attach a blank Post-it ™ to each output:

   ✁ *What story could a MechAnimation tell, if it was based on this pegboard mechanism?*

   ✁ *What could be drawn on each Post-It™ to illustrate the story?*

2. **Design Challenge: Make a MechAnimation and a story it can tell.** Students begin their designs of mechanisms and stories. They are not expected to finish these this period. Emphasize that these are initial ideas, like first drafts. After this lesson they will learn how to make mechanisms move the way they want them to move. Then they will make more MechAnimations in Lessons 10 and 11. Provide these directions:

   ✁ *Make an initial pegboard mechanism as a possible model for a MechAnimation. Draw the mechanism. Use arrows to show how it moves.*

   ✁ *Make changes in the pegboard mechanism. Change a pivot location or add an output. Draw the new mechanism.*

   ✁ *Write the ideas for a story you want to tell.*

Encourage students to continue designing and redesigning both their MechAnimations and their stories, until they come with something they like

Examples of student MechAnimations can be seen on the City Technology website at http://www.citytechnology.org/node/7. MechAnimations made by project staff are at http://www.citytechnology.org/stuff-that-works/design_puppets07.html.

**Science Notebooks**

- Draw at least two pegboard designs you tried. Explain what you like or don't like about each one.
- In words and pictures, describe the story your MechAnimation will tell.

## *Outcomes*

Students should learn to:

- create diagrams of alternative pegboard mechanisms,
- comment on their strengths and weaknesses, and
- invent stories that can be illustrated by their MechAnimations.

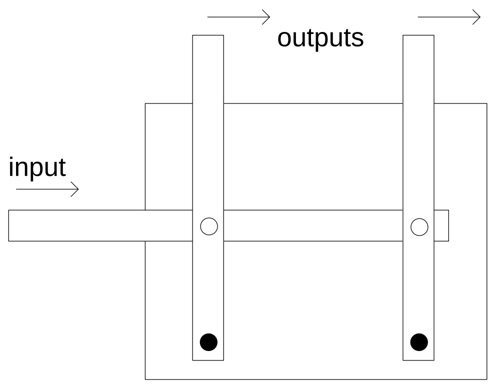
# Lesson 6: How do the outputs move?

## Overview

Motivated by a MechAnimation, Whale Chasing a Boat, students experiment with a mechanism that has one input and two outputs, and is shaped like the letter "H." They explore how moving the fixed pivots affects how the outputs move.

## Materials:

- **Windshield Wiper mechanism,** made from a pegboard base, three strips, two fixed pivots and two floating pivots (see diagram below). This Mechanism is called H3 because it looks like an H and uses third-class levers.

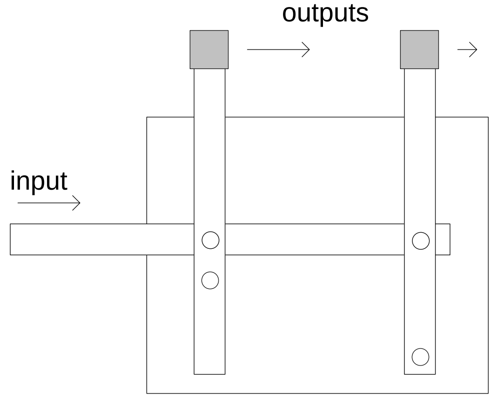



Windshield Wiper Mechanism

- **"Whale Chasing a Boat" Mechanimation**.
- **Pegboard base, three pegboard strips and four fasteners** per student.
- **Two Post-its™** for each student to attach to the two outputs.

## Procedure

1. **Demonstrate the Windshield Wiper mechanism**. Invite students to brainstorm what it could represent. They are likely to say it looks like windshield wipers.
2. **Demonstrate the "Whale Chasing a Boat" MechAnimation.** Ask students to the mechanism inside that makes the whale and boat move the way they do. Compare it to the windshield wiper mechanism you have just shown them.
3. **Setting-up for the H experiments.** The H mechanism is similar to the Windshield Wiper Mechanism, except that the fixed pivots are in different places. See the diagram below or visit http://citytechnology.org/node/1668 and http://citytechnology.org/node/1669.




An H Mechanism

Distribute the pegboard materials**,** pivots, Post-Its ™  and tape, and show students how to assemble an H mechanism:

a) Use two numbered links as the outputs. The input link may be either plain or numbered.

b) Place a floating pivot between the 5″ and 6″ holes of one output link and connect it to the end of the input link.

c) Place a floating pivot between the 5″ and 6″ holes of the second output link and connect it to the middle of the input link. It will look like an **H** with an input handle extending to the left.

d) Connect one of the outputs to the base through the 4″ hole, and connect the other output to the base through the through the 0″ hole.

e) Stick a Post-It™  to the top of each output link.

4. **Carrying out an H experiment.** Each student should operate the input of an H mechanism, and observe the movement of each output as the input moves back and forth.

**Science Notebooks**

✁ Make a drawing of the mechanism you made.

✁ Show the fixed pivots and floating pivots and use arrows to show how the input and outputs move.

✁ Write “more” next to the output that moves more.

✁ How does this compare to the Whale Chasing the Boat?

5. **Quick Share:** Ask two students to demonstrate their mechanisms and tell a story it might animate. Have them point out the fixed and floating pivots, and compare the amount of movement of the two outputs.

6. **More H experiments.** Ask students to remove the fixed pivots and do two more experiments:

a) Put a fixed pivot through the 2″ hole of one lever and a fixed pivot through the 7″ hole of the other lever.

b) Put the fixed pivots anywhere you wish.

**Science Notebooks**

- Make drawings of the two additional mechanisms you made.
- Show the fixed pivots and floating pivots and use arrows to show how the input and outputs move.
- Write "more" next to the output that moves more.
- What stories could your mechanisms tell?
- What happens when the fixed pivot and floating pivot are close together?
- What happens when the fixed pivot and floating pivot are farther apart?

**7.** **Class discussion** about how inputs and outputs move. Students bring their last mechanism to the class meeting. They are to be used to illustrate points students make about how the input and outputs move.

*a) What did you discover about the movement of the input and the output?*

- *When do the input and output move in the same direction?*
- *What difference does the location of the fixed pivot make for the direction the output moves?*

*b) What did you discover about how much the output moved?*

- *What difference does the location of the fixed pivot make for the amount the output moves?*

8. **Complete the Lesson 6 Worksheet:** How the Outputs Move. Insert the worksheet in the Science Notebook.

## *Outcomes*

Students should develop the following generalizations about the **directions** the outputs move:

- When the fixed pivot is between the floating pivot and the output, the input and output go in opposite directions.
- When the floating pivot is between the fixed pivot and the output, the input and the output move in the same direction.

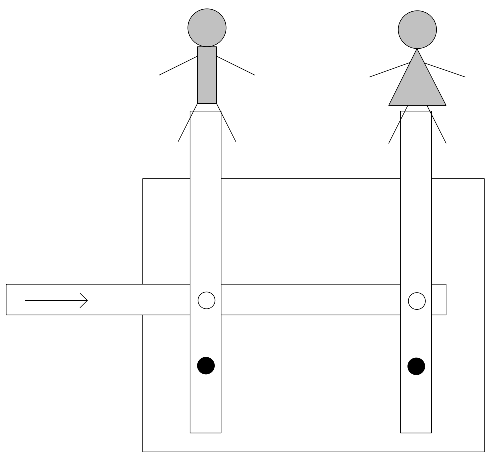
Students should learn these ideas about the **amounts** the outputs move:

- When the fixed pivot and floating pivot are moved closer together, the output moves more.
- When the fixed pivot and the floating pivot are moved further apart, the output moves a shorter distance.

Name: ____________________ Date: ________________

# Lesson 6 Worksheet: How the Outputs Move

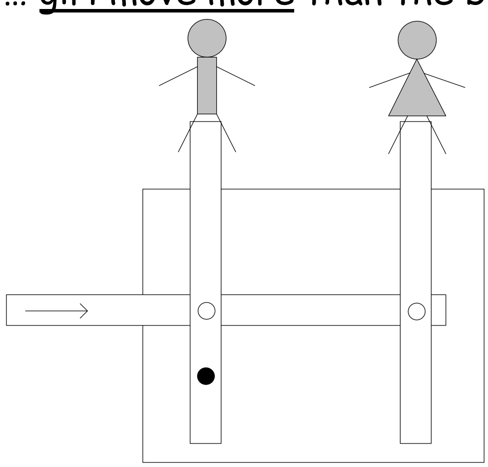
1. Use arrows to show how the boy & girl will move when the input goes to the right:



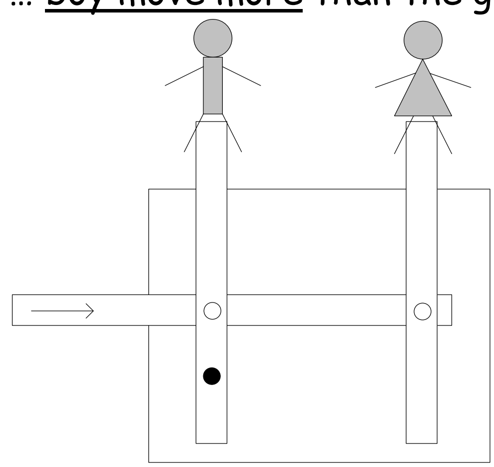
Explain in words how this mechanism works:

2. Now suppose you wanted the boy and girl to move different distances in the same direction, when the input goes to the right. Show where you would put the missing fixed pivot to make the …

… girl move more than the boy:



… boy move more than the girl:



Use arrows to show the movement of the boy & girl in each case.

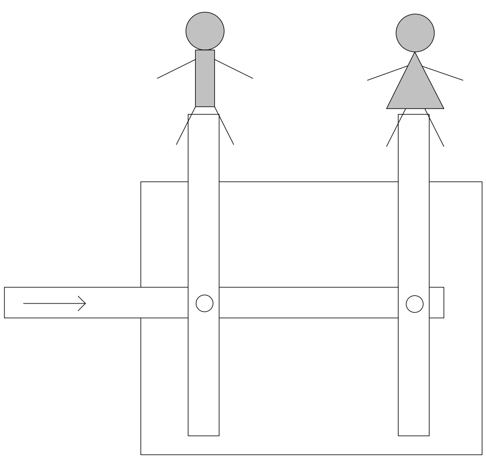
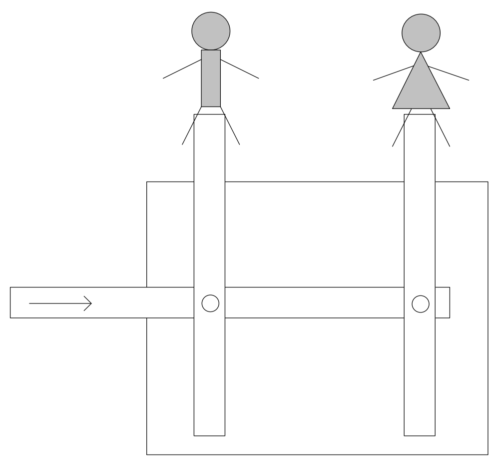
Name: __________________ Date: ______________

# Lesson 6 Worksheet, continued

To make an output move more than the other, its fixed pivot has to be ________________________________________________.

To make an output move less than the other, its fixed pivot has to be ________________________________________________.

3. What if you wanted to make the boy and girl move in opposite directions, when the input goes to the right. Show where you would put both fixed pivots to make the …

| … girl and the boy move towards each other: | … girl & boy move away from each other: |
| --- | --- |
|  |  |

Use arrows to show the movement of the boy & girl in each case.

To make two outputs move in opposite directions, their fixed pivots have to be____________________________________________.

To make an output move in the same direction as the input, its fixed pivot has to be________________________________________.

To make an output move in the opposite direction from the input, its fixed pivot has to be_____________________________________.

# Lesson 7: Ratio Machine I

## Overview

The Ratio Machine is a pegboard device students use to experiment with ratios and find proportions. Students see ratios in a concrete form that they can manipulate. In Lesson 6 Students made qualitative generalizations about the movements of inputs and outputs. In Lessons 7 and 8 these generalizations become quantitative. Students move the input 1″, 2″ and 3″; and measure how far the output moves in each case. They find the ratio of the distance moved by input to the distance moved by output. They compare this ratio to the ratio of the length of the input arm to the length of the output arm.

## Materials

- **Large data sheets** to record class data for Experiments A and B – two for each.
- **Pegboard base, 3 numbered links, 1 link without numbers, 3 pivots** per pair of students
- **Post-its ™** or masking tape to mark the output starting point
- An assembled **Ratio Machine** (see Directions on next page).

## Procedure

1. **Introduce and demonstrate the Ratio Machine.** The Ratio Machine makes it easy to find out how far an output will move, when the input is moved a set distance, such as 1″, 2″ or 3″. Students can use this knowledge to design their MechAnimations.

   Demonstrate how the Ratio Machine works and the measurements the students will make. Follow the directions below, or at http://citytechnology.org/node/91.

   The input and output are both horizontal, unlike in previous work, so explain that:

   ✁ The input link is the link nearest the bottom of the Ratio Machine and is the one that students move. They will try three different locations: 1″, 2″, and 3″ from the starting point.

   ✁ The output link is the upper link in the Ratio Machine. Students measure how far the output link moves when they move the input link to each of its three new locations.

   Review the steps students will follow. Emphasize the importance of careful measurements.

   ✁ Keep both the input link and output link horizontal.

   ✁ Line up the 0″ mark on the input link with the left edge of the base.

   ✁ Place a marker on the output arm, even with left edge of the base, to mark the starting position of the output.

   ✁ Move the input 1″ to the left, so its 1″ mark lines up with the left edge.

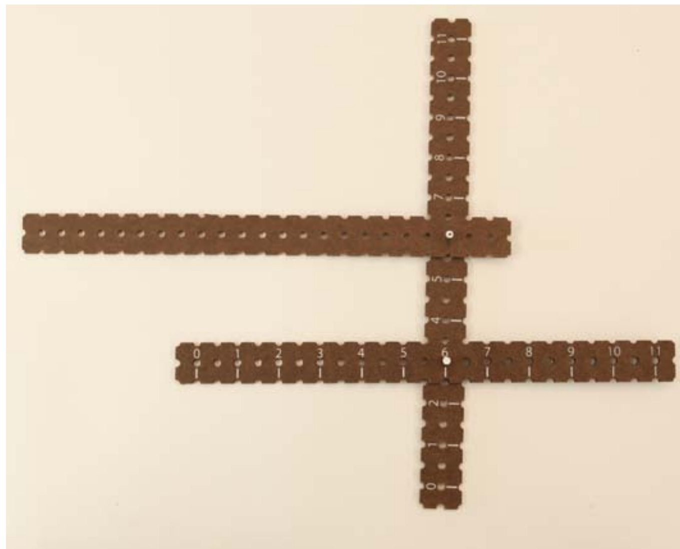
As you demonstrate, review the measurement techniques by asking students:

✄ *How do I figure out how far the output moved?*

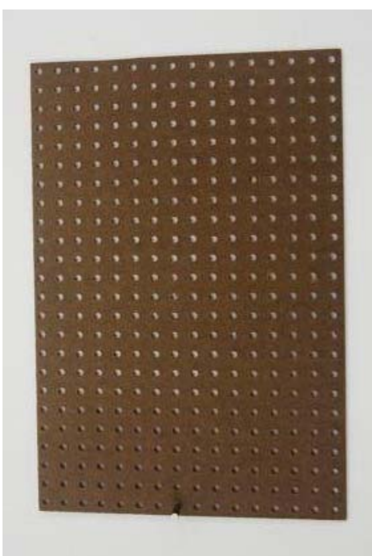
✄ *Where do I make the measurement?*

**Directions for Making Ratio Machines**

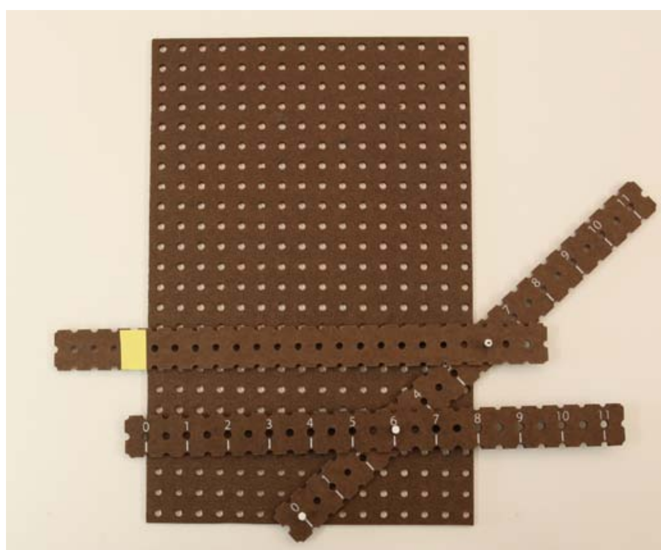
a) Place pivots skinny end up through the holes at 3″ and 6″ on the vertical link



b) Place the 6″ hole of the (lower) input link over the lower pivot and place the (upper) output link over the upper pivot, 3 holes from its right end



c) Place a pivot up through the base, in the bottom row, in the eighth hole, counting from the left edge. This will be the fixed pivot.



d) Place the 0 ″ hole of the vertical lever over the fixed pivot. Move the input link so the 0 ″ mark lines up with the left edge. Keep input and output arms parallel to the holes in the base. Mark the output link with a Post-it™ or tape, even with the left edge of the base. This is the starting position.

2. **Make the Ratio Machines.** Provide each pair with a pegboard base, 4 links, 3 pivots and 2 Post-its ™. Each pair should assemble their ratio machine, as you demonstrate each step. Instructions for making a machine are provided above, as well as on video at http://citytechnology.org/node/967.

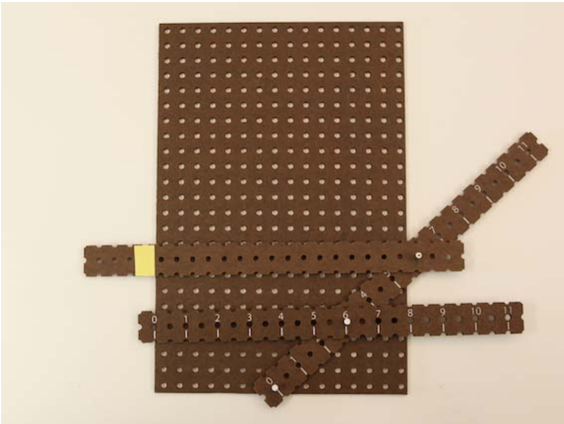
3. **Demonstration Experiments with the Ratio Machine.** Demonstrate the two experiments, as the students following you on their own Ratio Machines. The video "Doing Experiments A and B" demonstrates doing these experiments. See http://citytechnology.org/node/968.

   a) Move the input (lower) link so the 0″ mark lines up with the left edge.

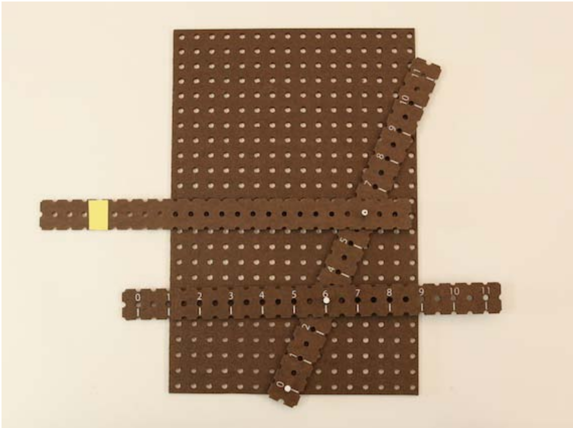
   b) Keep input and output arms parallel to the holes in the base.

   c) Mark the output link with a Post-it™ or tape, even with the left edge of the base. This is the starting position (see left photo, below).

   d) Move the input 1″ to the left. Carefully line the 1" mark with the left side of the base (see right photo, below). Use a numbered link to measure how far the output link moved.



Set-up: Input at 0 ″, output link marked by tape where it crosses left side of base.



Measurement: Input pulled out 1 ″ to the left; output mark has moved about 2 ″ to the left

The results of the measurement should be 2″, but some students' results may not be correct. Ask a student who did get the correct measurement to demonstrate how he or she did it, and provide assistance until everyone knows how to do it.

Then demonstrate a second measurement:

Move the input back so the 0″ mark lines up with the left edge of the base. The marker on the output arm should still line up with the left edge. If not, move it so it does. Now ask students to predict how far the output will move when the input is moved 2″.

Ask all the students to perform this same measurement:

✁ *Move the input 2″ and see how far the output moves.*

4. **Doing Experiment A.** After students have understood the demonstration of using the Ratio Machine, distribute the Worksheet: <u>Ratio Machine Experiments A and B</u>. Then provide directions for doing the experiment.

   a) Review the experiment sheet with them. There are two terms that are new: "input arm" and "output arm." Ask students what they think each term means.

      - The **input arm** is the distance from the fixed pivot to the floating pivot that connects to the input (i.e., where the input link is attached to the lever).

      - The **output arm** is the distance from the fixed pivot to the floating pivot that connects to the output (i.e. to where the output link is attached to the lever).

   b) Explain where students should record their data on the workheet.

   c) Although students have already done the first two measurements of Experiment A, They should begin at the beginning and do all three measurements, so they can record new data.

   d) Use a large chart to record the Experiment A data from all students. There will probably be a lot of differences among the students' data. Discuss how they made their measurements and why they think they got different results. See the <u>Troubleshooting</u> section for ideas about how to address some of the issues that might have arisen.

5. **Doing Experiment B.** This is similar to the previous experiment, except that the output arm is 9″. Show students where the experiment sheet says this. Then demonstrate how to change the output position on the lever from 6″ to 9″. Provide the following suggestion:

   - Remove the three links from the base.  Take the pivot from the 6″ hole of the vertical link (lever) and move it up to the 9″ hole. Move the output link to the 9″ mark and reconnect it there. Replace the 0″ hole of the lever over the fixed pivot on the base.

   Review the worksheet, and then ask students carry out Experiment B.

   After students complete Experiment B, Record the class data on a large chart and discuss reasons for differences in results. When discussing the data, don't try yet to find patterns for either Experiment A or B data. Rather, these discussions are aimed at improving measurements and understanding of the experiment.

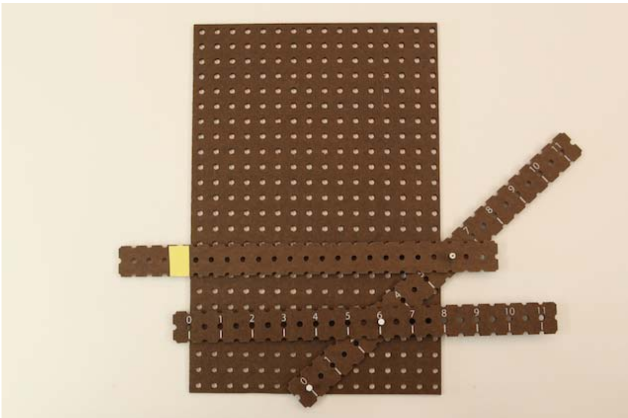
6. **Repeat Experiments A and B.** Collect the worksheet and distribute new ones. The students will now have a chance to repeat Experiments A and B and should be much more careful in their measurements. Explain that since all the students will be doing the experiments the same way, their results should come out the same. After the experiments are done again, repeat the collection of class data for Experiments A and B on a large chart. If there time permits, look for patterns in the data with the class. This video shows one way to analyze data: http://citytechnology.org/node/971. Otherwise, this can be left for homework, or serve as the starting activity of Lesson 8.

**Science Notebook**

- Attach the Worksheet to your Science Notebook.
- Describe the  patterns you have found in your data.

Name:______________________________Date:_____________

# Lesson 7 Worksheet: Ratio Machine Experiments A & B



**Experiment A**

Fixed pivot at 0"  Input arm = 3"  Output arm = 6"

| Distance input moves | 1" | 2" | 3" |
|---|---|---|---|
| Distance output moves | | | |

*Looking for Patterns:*

The input arm (3") is half the output arm (6").
What other pair of numbers in Experiment A can you find, where one number is also half of another number ? ________________________

**Experiment B:**

Fixed Pivot at 0"  Input arm = 3"  Output arm = 9"

| Distance input moves | 1" | 2" | 3" |
|---|---|---|---|
| Distance output moves | | | |

*Looking for Patterns:*

What is the ratio between the input arm and the output arm ? ____
What other numbers in Experiment B are in that same ratio?

__________________________________________________

## *Outcomes*

Students will learn how to:

- Set up two quantitative experiments with the Ratio Machine, adjusting the input and output arms as needed,
- correctly measure the distances moved by the input and the output, and
- collect and record quantitative data.

## *Troubleshooting*

There are several sources of error in these experiments. Student errors provide opportunities to re-teach aspects of measurement, the importance of following directions, and the need for care in conducting an experiment. Here are four sources of errors and links to further descriptions of each one:

- **Measuring from the end of the ruler rather than the 0″ mark**: The numbered links simplify measuring, because they are show only ½″ increments, rather than anything smaller. However, as on most rulers, the 0″ mark is not at the end. When students measure from the end of a numbered link, their measurements will be too large by ½″. For more information, please visit http://citytechnology.org/node/1041
- **Careless measurements of starting and ending points:** Significant error can occur if the input link is not carefully adjusted so the 0″, 1″, and higher marks line up with the edge of the base, when viewed from directly above. See http://citytechnology.org/node/1039 for further details.
- **Incorrect placement of input or output link.** This error most often occurs when changing the connections from Experiment A to Experiment B. There is a discussion of this issue at http://citytechnology.org/node/1037
- **Failure to hold the input and output links horizontal**. View information about this problem at http://citytechnology.org/node/1042

# Lesson 8: Ratio Machine II

## Overview

In Lesson 7 students did Experiments A and B with the Ratio Machine. In this lesson, students consider the variables in these experiments: input arm length, output arm length, distance moved by input, and distance moved by output. They analyze the data from Experiments A and B, to find a pattern that relates these four variables. Then they carry out Experiments C and D, analyze these data and generalize the patterns they find.

## Materials

- **Large data sheets** for Experiments A and B, Lesson 7
- **Large data sheets** to record class data for Experiments C and D.
- For each pair: a **Ratio Machine** from Lesson 7.

## Procedure

1. **What is an experiment?** Based on the experiences students have just had in doing Experiments A & B**,** lead a discussion on what it means to do an experiment:

   - *What were you trying to find out about?*
   - *What data did you collect?*
   - *What did you change each time you took new data?*
   - *In each experiment, what did you keep the same during the whole experiment?*
   - *What did you change between experiments?*

   Ask students to think about what the term **variable** means.  Then ask:

   - *What were the variables in our Ratio Machine Experiments?*
   - *Why do we change some variables and keep others the same?*
   - *What can we learn from an experiment?*

   Continue collecting examples of variables until students have identified the four variables. Emphasize that variables are things the students changed, or things that resulted from the changes they made. A video, “Doing an Experiment” is at http://citytechnology.org/node/970.

**Science Notebooks**

- List the variables in Experiment A.
- Which variable did you change?
- Which variable did you measure?
- Which two variables did you keep the same during each experiment?

2. **Analyzing data from Experiment A.** Pick up where the class stopped at the end of Experiment A. Post the class data sheet, and ask: Then ask;

   ✂ *Why are some students' data different from others'? What might have happened?*

   ✂ *Which of the results do you think is the more accurate? Why do you think so?*

   ✂ *What pattern do you see in these numbers?*

   If no one offers a pattern say

   ✂ I think I see a pattern in the data. It looks like the output moves twice as far as the input.

   Circle the student data that fit this pattern. Once everyone sees the pattern, ask:

   ✂ *What other numbers do you see where one number is twice as much as the other?*

   Help them notice that:

   ✂ **The output arm is twice as long as the input arm** *and*

   ✂ **The output moves twice as far as the input.**

   A video about analyzing student data is available at: http://citytechnology.org/node/971.

3. **Analyzing data from Experiment B.** Ask:

   ✂ *What pattern do you see in the data from Experiment B?*

   Help students notice that in Experiment B,

   ✂ **The output arm is three times as long as the input arm *and***

   ✂ **The output moves three times as far as the input.**

4. **Experiments C and D.** Distribute the Worksheet: Ratio Machine Experiments C and D.

   Review the Worksheet with the class, then ask:

   ✂ *What you will do to set up for Experiment C?*

   ✂ *What is the first measurement you will make?*

   ✂ *What will you do after that?*

   ✂ *What pattern can you predict for the results?*

   ✂ *After you complete Experiment C, what will you change in order to do Experiment D?*

   Ask students to do Experiment C and then D, and record their results on the Worksheet..

5. **Analyzing data from Experiments C and D.** Record each pair of students' data on the class data sheet for Experiment C. If students got different results, ask:

   ✂ *Which of these results do you think is most likely correct? Why?*

   Circle the data sets where the output is twice the input.

   ✂ *What patterns do you see in the Experiment C data?*

When students see that output movement is twice the input movement ***and*** output arm is twice the input arm, proceed to collect Experiment D data on the class data sheet. Review some possible reasons why different students might have different data.  Then highlight valid data: circle the numbers where the output is three times the input.

✃ *What patterns do you see in the Experiment D data?*

✃ *What is the relation between the input arm, 3 ½" and the output arm, 10 ½" ?*

Most students will not see that 3 ½ x 3 = 10 ½, so spend some time helping students think about this relationship. The output arm is also three times the input arm, just like the results for the movement of output and input.

**Science Notebook**

✃ Attach the Worksheet to your Science Notebook.

✃ What pattern did you see in Experiment C? Compare this to Experiment A.

✃ What pattern did you see in Experiment D? Compare this to Experiment B.

✃ How can you use these patterns when you design your MechAnimation?

## Outcomes

Students should have these understandings about the experiments they have done:

✃ They did an **experiment** when they took measurements on the Ratio Machine, recorded them and analyzed them.

✃ The purpose of each experiment was to find out how far the output moved when the input was moved a specified amount.

✃ The input and output arm didn't change during the experiment.

✃ Each experiment had four variables:

1. **Input arm** and b) **output arm** lengths. Neither one changed during an experiment.

c) **Distance the input moved**, which they changed before making each measurement, and

d) **Distance the output moved**, which they measured after they moved the input.

Based on the results of the experiments, students should have learned that:

✃ If the output arm length is twice the input arm length, then the output will move twice as far as the input

✃ If the output arm length is three times the input arm length, then the output will move three times as far as the input.

✃ If I want one of the outputs on my MechAnimation to move twice as far, then I should shorten the input arm by half. If I want the output to move half as far, I should double the input arm.

## Troubleshooting

See the troubleshooting section of Lesson 7.

Name:______________________________Date:_____________

## Lesson 8 Worksheet: Ratio Machine Experiments C and D

**Experiment C**

Fixed pivot at 0″        Input arm = 5″        Output arm = 10″

| | | | |
|---|---|---|---|
| Distance input moves | 1″ | 2″ | 3″ |
| Distance output moves | | | |

***Looking for Patterns:***

How are the results of Experiment C similar to those of Experiment A?

_______________________________________________________

Why do you think they are similar? ___________________________

_______________________________________________________

**Experiment D:**

Fixed Pivot at 0″        Input arm = 3 ½″        Output arm = 10 ½″

| | | | |
|---|---|---|---|
| Distance input moves | 1″ | 2″ | 3″ |
| Distance output moves | | | |

***Looking for Patterns:***

How are the results of Experiment C similar to those of Experiment A?

_____________________________________________________

Why do you think they are similar? ___________________________

_______________________________________________________

# Lesson 9: Investigating Force and Buckling

## Overview

The cardstock inputs of MechAnimations often buckle when pushed in. In this lesson, students investigate the force on an input link and ways they can make the input link sustain more force without buckling. They experiment with a Force Probe to

- reduce the friction in a mechanism;
- investigate the force needed to move the output; and
- find out how this force depends on the length of the input arm.

## Materials:

- **Pegboard base**, **link** and **rivet** for each pair of students.
- **Force probes,** cut from Force Probe Template; one template for each pair of students,
- **Sample Mechanism with a buckled input**.

## Procedure

1. **Class discussion of force and friction.** Demonstrate a pegboard base with a third-class lever. Make this by attaching a link to the base with a fixed pivot through the 0″ hole and a hole near the bottom of the base, held horizontally. Compare this to an output of a very simple MechAnimation. Push it with your forefinger. Ask:

   - *What might make it harder to push this lever?*

   The push that moves the lever is a **force**. If the pivot is too tight, or it is rubbing against the base, **friction** will be resisting the force you apply when pushing the lever. Lead students to analyze the places where friction interferes with movement of the lever. Two such places are a) between the lever and the pivot and b) between the lever and the base. Ask:

   - *What could you do to reduce the friction?*

   Students may suggest ways to make the lever fit more loosely on the pivot. They may also suggest things to insert between the lever and base, such as glossy paper.

   - *How could you tell if you reduced friction even a little bit?*

2. **The Force Probe**. This an 8 ½″ x 1″ piece of cardstock that is used as an input to push the lever. From the cardstock template, you can cut 10 Force Probes. It is used to gauge the amount of force needed to push a lever. The greater the force required, the greater the difficulty in pushing with the Force Probe.

   Hold the Force Probe at its 8″ mark and use its left end to push the lever at its 5″ mark. The force probe will buckle and fail to move the lever. Ask:

   - *How do you know that there is force on this Force Probe?*

Introduce the term **buckle** to describe the bending of the Force Probe when pushed from one end, against resistance at the other end.

✁ *Suppose you don't want the Force Probe to buckle when you push the lever at the 5″ point. What could you do?*

Students may suggest holding the Force Probe closer to the end. Define the **length of the Force Probe** as the distance from where it you hold it to the end that pushes on the lever. After a brief discussion, hold the Force Probe at 1″ and again try to push the lever at its 5″ mark. When the length of the Force Probe is 1″, it should be able to move the lever without buckling. Review the results of this demonstration:

✁ **The Force Probe buckles when it is 8″ long, but not when it is 1″ long.**

Ask students to predict:

✁ *What is the shortest length that will make the Force Probe buckle as it pushes the lever?*

Experiment with the lengths they suggest. At some point, the Force Probe will just begin to buckle.

3. **How does force vary with input arm?** Summarize the results of the previous experiment using the term **input arm**:

✁ The Force Probe starts to buckle when it is **___** long, when I push on the lever at its 5″ mark. The distance from the fixed pivot to where I push on the lever is called the **input arm**, so 5″ was the length of the input arm.

Make a chart showing two columns, "Input Arm" and "Force Probe Length" and record the result for Input Arm of 5″. Then ask about the effect of changing the input arm:

✁ *If I wanted to increase the input arm to 11", what would I have to do differently?*

✁ *How do you think things would change with the Force Probe, if the input arm was 11″ instead of 5"?*

Gather a few predictions. Students might suggest that it would be easier to push with an input arm of 11″, or harder, or the same. If it was easier, the Force Probe would not be as likely to buckle, and *vice versa*.

Then use a new Force Probe to push the lever at its 11″ mark. Hold the Force Probe so its length is first 1″, then 2″, etc. until it first begins to buckle. Record the result on the table you have created, showing the Force Probe Length (before buckling) for an Input Arm of 11″. Ask students what they have learned from these results:

✁ *What changes when I increase the input arm?*

✁ *What do you think would change if I made the input arm shorter?*

Help students develop the following generalizations:

✁ **A longer Force Probe buckles more easily.**

✁ **A shorter Force does not buckle as easily. This means it can exert more force.**

✁ **If the input arm is longer, the Force Probe buckles at a longer length, and *vice versa*.**

✂ **A longer input arm requires less force (not as likely to buckle) and a shorter input arm requires more force (more likely to buckle).**

4. **Setting up for the Experiments with the Force Probe.** Students will measure force by the length of the Force Probe when it first buckles as it pushes the lever. Distribute a link, base and rivet, and 10 Force Probes, to each pair of students. Show them how to make the same kind of lever you have been using:

   ✂ Attach the link to the base with a fixed pivot through the 0″ hole and a hole near the bottom of the base.

5. **Effect of friction.** Students should begin by making a Force Probe measurement before they have done anything to try to reduce the amount of friction. The measurement consists of seeing the length of the Force Probe when it just starts to buckle. Then they should try to make the lever move more easily, by reducing the friction between the lever and the pivot and between the lever and the base. The second measurement with the Force Probe should be different, if the amount of friction has changed.

**Science Notebook**

✂ What did you do to reduce the friction between the lever and the pivot?

✂ What did you do to reduce the friction between the lever and the base?

✂ How did you know that the friction was reduced?

✂ What variables did you have to keep the same to be sure that the only thing you changed was the amount of friction?

Students should recognize that the amount of friction is reduced is if less force needs to be exerted to move the lever. They should be able to tell that less force was needed, because the Force Probe didn't buckle as easily – its length could be longer and it could still avoid buckling.

6. **Changing the input arm.** Distribute the Worksheet and explain how to use it. Remind students about the term **input arm**: the distance from the fixed pivot to the point on the lever where the input is made. In this experiment the input arm is the distance from the fixed pivot to where the Force Probe pushes on the lever.

   a) *Hold the Force Probe at the 1" mark. Push the lever at the 11" end. If it does not buckle, hold the Force Probe at the 2" mark and push the lever, still at the 11" point. If the Force Probe does not buckle hold it at greater distances, such as 3", 4", etc., until the probe buckles. On the Worksheet, draw the buckled force probe and record its length when it buckled.*

   b) *Repeat this experiment. Push on the lever at its 9" mark. Draw the Force Probe and record its length when it first buckled. Repeat the experiment three more times: at the 7", 5" and 3" marks on the lever. Each time begin holding the force probe at 1" from its end, push the lever, and if it does not buckle, move your fingers 1" further out on the Force Probe and push the lever again. Continue to hold the Force Probe at greater lengths until the probe buckles when it pushes the lever. Then draw the force probe and record the distance when the force probe first buckled.*

After students have recorded the results on the Worksheet ask them respond to the question at the bottom of the worksheet.

7. **Force and distance results** Hold a class meeting to discuss the results. The results will vary from one student to another. For example, some students may find that with an input arm of 11″, the Force Probe first buckles at a length of 5″, while others may say this happens at a length of 8″ or more. These differences reflect different amounts of friction that resist the movement of the lever.

   Less important than comparing one student to another is to look at the pattern each student finds for the Force Probe Length as they decrease the input arm. Record the data on a class data chart for each pair of students. It might look something like this:

| | Student pair # | **Input arm** | | | | |
|---|---|---|---|---|---|---|
| | | **11″** | **9″** | **7″** | **5″** | **3″** |
| Lengths of Force Probe found by different pairs of students | 1 | 6″ | 5″ | 5″ | 3″ | 3″ |
| | 2 | 8″ | 7″ | 6″ | 4″ | 3″ |
| | 3 | 7″ | 7″ | 5″ | 4″ | 3″ |

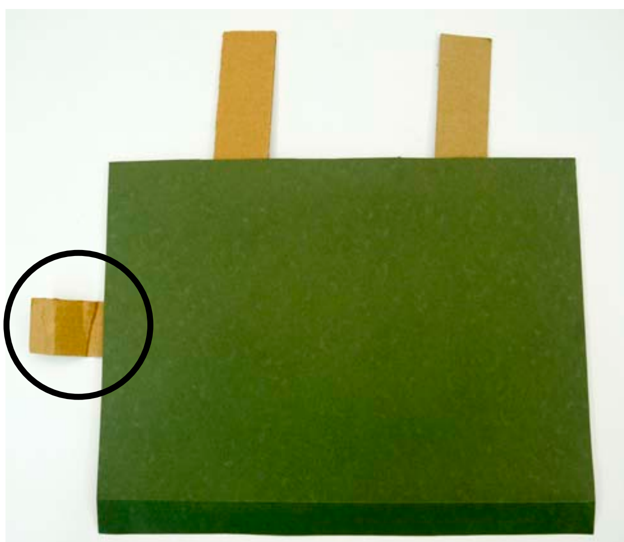
The important pattern is that as the input arm gets shorter the Force Probe buckles at shorter lengths. This means that an input must exert a greater force to move a lever when the input arm (the distance to the pivot) is shorter. Help students reach these generalizations:

✂ **The shorter the input arm, the shorter the Force Probe must be to keep it from buckling.**

This is true because:

✂ **The shorter the input arm, the more the force needed through the Force Probe.**

8. **Using these results in designing MechAnimations.** Demonstrate a mechanism like the one shown below:



This is like a MechAnimation before it has been decorated. Ask:

- *What is similar to the Force Probe in this mechanism?*
- *What are the forces that the input must overcome?*

Students should conclude that the input link of the MechAnimation is similar to the Force Probe. The friction is not only between each of the two levers and the fixed pivots, but there is also friction between the input and the floating pivots and between the two levers (output links) and the cardstock that covers them.

**Extension: Modifying the Force Probe to Make it Stronger.** Ask students:

- *How could you change the Force Probe so it could take more force?*

After taking suggestions, tell students they will experiment with two different ways to change the Force Probe:

- Use two of the 8 ½” x 1” Force Probes together. (If they wish, students may glue them, tape them, or just hold them together)
- Use one 8 ½” x 1” strip, crease it length-wise down the middle with a ruler and ball point pen, then fold it length-wise and make a sharp crease.

Then ask students to repeat the experiment they have just done, but with the improved Force Probe. They should record their results for both the two strips together and for the folded strip. They should find that the folded probe can exert much more force than the doubled probe. Ask:

- *How can this result be used in the design of your MechAnimation?*

## Outcomes

Students learn these ideas about how the amount of applied force is reflected in the buckling of the Force Probe:

- The Force Probe indicates the amount of force needed, by the extent to which it buckles.
- If the Force probe buckles, then it takes more force than the Force Probe can withstand to move the lever at a particular point.
- If the Force Probe doesn’t buckle, then the force required is within the amount the Probe can support.

Students should learn how the amount of force varies with the input arm of a lever:

- The greater the input arm, the less force is needed to move the lever.
- The shorter the input arm, the more force is needed to move the lever.

Through the Extension activity, students should discover that folding an input link lengthwise makes it much more resistant to buckling, and therefore capable of withstanding a larger force.

Name: ___________________________Date:__________________

# Lesson 9 Worksheet:
# How does the force change with Input Arm?

| Input arm length | Draw what the Force Probe looked like when it buckled | Length of the Force Probe when it buckled |
|---|---|---|
| **11"** | | |
| **9"** | | |
| **7"** | | |
| **5"** | | |
| **3"** | | |
| What did you discover about the force needed to move the lever at different input arm lengths? ________________________________ ________________________________ ________________________________ ________________________________ | | |

# Force probe Template

Directions: 1. Print or photocopy onto cardstock. 2. Cut along dashed lines to make 10 force probes

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

1 2 3 4 5 6 7 8

# Lesson 10: MechAnimations II

## Overview

Students refer to their science notebooks for the MechAnimation ideas they began in Lesson 5. They continue developing ideas, stories, and mechanisms for a MechAnimation. By the end of the period they should have a pegboard model for their MechAnimation and a story to go with it. Some students may have begun to create their MechAnimations in cardstock

## Materials:

✁ **Pegboard bases**, **links** and **pivots** as needed

✁ **Cardstock, paper fasteners, cardboard for bases, scissors.**

## Procedure

1. **Class discussion of MechAnimations ideas.** Students share the MechAnimation ideas they recorded in Lesson 5. They talk about how their first ideas have changed. If their new ideas require mechanisms they don't know how to make, have them describe or sketch what they want the mechanism to do. The Troubleshooting section below provides some solutions to construction problems. After students have helped one another, have them begin with their own work. They continue to make and decorated pegboard mechanisms and to develop the story to go with them. Students who have developed their ideas may begin to make the MechAnimations in cardstock.
2. **Work Session**. Students work on their mechanisms and stories. Those who have fully developed mechanisms and stories may begin to make the MechAnimations with cardboard bases and cardstock. There will need to be a place for them to store this work in progress.

   **Science Notebooks**

   ✁ Draw the pegboard mechanism you will use for your MechAnimation.

   ✁ In words and pictures, describe the story your MechAnimation will tell.

3. **Class discussion.** This is a quick sharing of the work that one or students have done with emphasis on the science notebook record of the work. Remind students to draw their mechanisms carefully so they will know where to start the next time they work on the MechAnimations.

## *Troubleshooting:*

Some of the questions students may have about making a mechanism with particular kinds of outputs are answered in the links to 1. and 2. below. The questions in 3. – 5. address particular questions about going from pegboard mechanisms to MechAnimations. These too are answered in the associated links.

1. How do you make one input move outputs on both sides of the input?
    - Outputs directly across from each other that move up and down together, like arms and legs, and that are connected to the same place on the input. http://www.citytechnology.org/node/921.
    - Outputs that are offset from one another and connected to different places on the input. http://www.citytechnology.org/node/931.
    - Outputs that are opposite ends of the same link. One moves up when the other moves down. http://www.citytechnology.org/node/901.
2. How do you make an output move at right angles to the input. When the input moves up and down, the output moves in and out at the side. http://citytechnology.org/node/911.
3. How do you make a cardboard MechAnimation from a pegboard model? http://www.citytechnology.org/node/941
4. What materials are best for making a cardboard MechAnimation? http://www.citytechnology.org/node/961
5. Can the cardboard base for the MechAnimation be a different size and shape than the pegboard base? http://www.citytechnology.org/node/951

# Lesson 11: MechAnimations III

## *Overview*

Students complete the MechAnimations they were working on in Lesson 10. They transfer the pegboard mechanism to cardstock, decorate it and complete the story that accompanies the MechAnimation.

## *Materials*

✄ **Science Notebooks** with drawings and stories Lesson 10.

✄ **Cardstock MechAnimations begun in Lesson 10.**

✄ **Pegboard bases**, **links** and **pivots** as needed

✄ **Cardstock, paper fasteners, cardboard for bases, scissors.**

✄ **Numbered strips** to determine coordinates**.**

✄ **Craft materials** for decorating MechAnimations

## *Procedure*

1. **Mini-lesson on transferring a pegboard model to cardstock.** Demonstrate a way, appropriate to your class, to transfer a pegboard mechanism to cardstock that will insure that the cardstock MechAnimation moves the same way as the pegboard mechanism. The first method uses one-to-one correspondences. The second method uses measuring and coordinates.

   <u>One-to one correspondences</u>:

   a) Place a cardstock strip over the pegboard input link. Mark the locations of the floating pivots.

   b) Place cardboard strips over each of the pegboard output links and mark the positions of the fixed and floating pivots on each. Number them and keep them in order.

   c) Punch holes for each of the pivots in each of the links.

   d) Connect the input link to the floating pivot hole of each of the output links.

   e) Place the linkages over whatever shape base is desired, keeping the output links in the same orientation as on the pegboard mechanism.

   f) Mark the positions of the fixed pivots, through the holes in the output links onto the base. Punch the holes for the fixed pivots with a ball point pen.

   g) Connect the output links to the base with fixed pivots.

   <u>Measuring and coordinates</u>

   The numbered strips are divided in ½” intervals that correspond to the spacing of the pegboard holes. They can be used to measure how far from the end of an input or output link a pivot is located. The strips can also be taped along the bottom and left side of the mechanism base, lining the numbers up with the holes of the pegboard, to provide a coordinate system.

a) Measure and record the position of each floating pivot on the input link.

b) Measure and record the position of the floating pivot and the fixed pivot on each output link.

c) Transfer the measurements in 1. and 2. above to the cardstock strips to be used as input and outputs.

d) Punch holes for each of the pivots in each of the links.

e) Connect the input link to the floating pivot hole of each of the output links.

f) Place the numbered strips along the edges of the base and read the coordinates of each fixed pivot.

g) Place the numbered strips along the edges of the cardboard that will be the MechAnimation base. Mark the locations of the fixed pivots, according to the coordinates recorded in 6, then punch these holes.

h) Connect the outputs to the base with fixed pivots.

2. **Making MechAnimations.** Students use one of the techniques for transferring their Mechanimations from pegboard to cardstock. They use craft materials to add decorations, based on the stories they have written.

# Lesson 12: Presentations of MechAnimations

## *Overview*

Students present and discuss the MechAnimations they have made. As part of their presentations, students share their processes of design and redesign.

## *Materials*

✁ Students' completed **MechAnimations** and stories.

## *Procedure*

1. **Designing the presentations**. The final products, the MechAnimation and the story it illustrates, are obvious parts of any presentation. However they do not reveal the work the students have done: the troubleshooting and problem solving, the designing and redesigning. We view the process students go through as more important than the final product. It is through the process that the learning occurs. Thus the Science Notebook is an integral part of the presentation. Each presentation should therefore include:

   a) A demonstration of the MechAnimation and how it works;

   b) Narration of the story that the MechAnimation illustrates;

   c) The Science Notebook, which should include:

      i. A brief history of the work:

      ii. The mechanisms and ideas they began with.

      iii. The vision of what they wanted to do,

      iv. The problems they encountered,

      v. The way they solved the problems,

      vi. The way their vision changed on the way to the final story and MechAnimation.

2. **Presenting MechAnimations:** In most classes the presentation of MechAnimations, the Science Notebook and their stories will be before their own classmates, or another class. Students may also wish to present their work to a broader audience. Some possibilities for a broader audience include:

   a) **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. The Science Notebooks can be posted too, as part of the same display.

   b) **Museum table**: For Parent-teacher Conferences, Open School Night, or other community events, the MechAnimations and Science Notebooks can be displayed on tables. Signs can invite viewers to see how the MechAnimations work, to read the stories they illustrate and to see in the Science Notebooks the history of their making. .

c) **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. Again, full emphasis is given to the Science Notebooks and their description of the process of designing and redesigning the MechAnimation.

**d) Puppet show:**

### *Extension 1: Measuring Force and Distance*

**Overview**

Students found in Lesson 9 that the closer the input (Force Probe) is to the fixed pivot, the more the input buckles. In Extension 1 this qualitative understanding is expressed in numbers: the force on the lever arm (measured in jumbo paper clips) times the distance of the force from the fixed pivot is always the same, as long as the lever arm is pulled down the same amount. Students' data support the law of the lever.

**Materials**

**For the class**

- Chart paper for recording data
- Force Machine and Force Probe for demonstration

**For each pair of students**

- Force Machine (see materials on next page)
- 12" link (not numbered) and stand
- Post-it ™ or small piece of masking tape
- 25 jumbo paper clips
- Experiment sheets for Experiments A and B

**Procedure**

**The Force Machine and its variables**

In Lesson 9 students saw that the input to a lever buckles more as it exerts force closer to the fixed pivot. In the experiments for Extension 1 students measure different combinations of force (measured in jumbo paper clips!) and distance that produce equal effects. They do this using the Force Machine. Here is a video on set-up of the Force Machine: http://citytechnology.org/node/983. Instructions on how to assemble the Force Machine are on the following pages. In some classes student assistants assemble the Force Machines for the class ahead of time.

In Lesson 9 students used a Force Probe made of a 1' x 8 ½" strip of cardstock to qualitatively measure how much force was needed to move a lever, pushing it at different distances from the fixed pivot. Use the same Force Probes to introduce the Force Machine to the class. Hold the Force Probe at 8" and push down on the Force Machine lever at its 11" mark. Point out that the 11" mark is only 9" from the fixed pivot. Depress the lever only to the horizontal. Repeat this test at the 10", 9", 8" . . . marks on the lever. Call attention to:

- The Force Probe buckles more (it exerts more force) as its distance to the fixed pivot (the input arm) decreases.
- The input arm (the distance to the fixed pivot) is 2" less than the number on the lever.

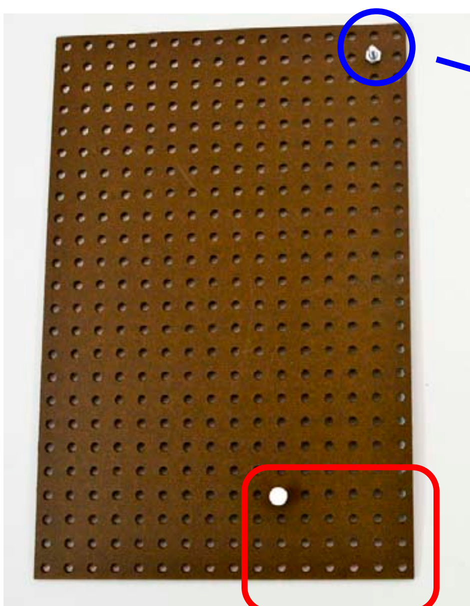
## How to Assemble the Force Machine

**Parts list**:

- Pegboard **base**.
- 12” x 1” numbered pegboard **link**– this will become the **lever**
- **Stand** to support pegboard base
- Two #16 **rubber bands**
- 25 Jumbo **paper clips**
- One each: 8-32 x ¾” machine **screw**; 8-32 **flat nut** and 8-32 **wing nut**
- One **rivet**, 5/8” length x 3/16” diam.

**Assembly Directions**

1. With the base held as in Figure 1 place the screw through the hole one to the left and one below the top right corner and tighten it to the base with the flat nut. Make certain that the screw is firmly attached, and cannot wobble or jiggle. See Figure 1 a). Place the rivet six holes to the left and four holes above the bottom right corner. See Figure 1 b).



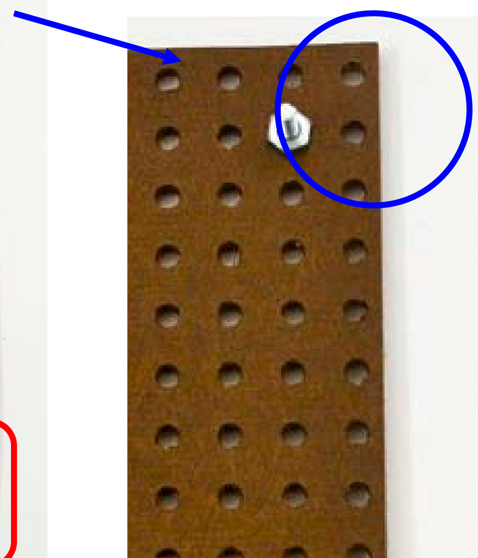
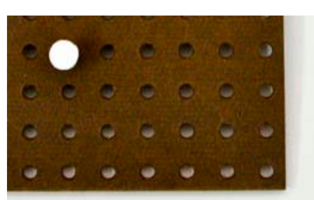


Figure 1: Base

a) detail showing screw fastened with flat nut



b) detail showing placement of rivet

Place the pegboard link on the screw through the link's 2" hole. Then screw the wing nut loosely on the screw to hold the lever so it can rotate freely (Figure 2).

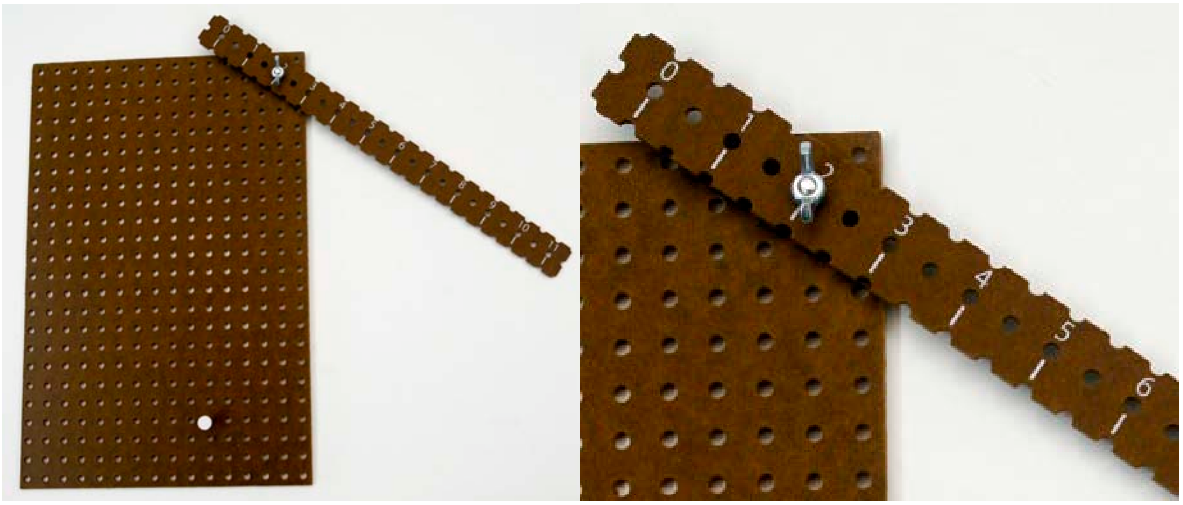
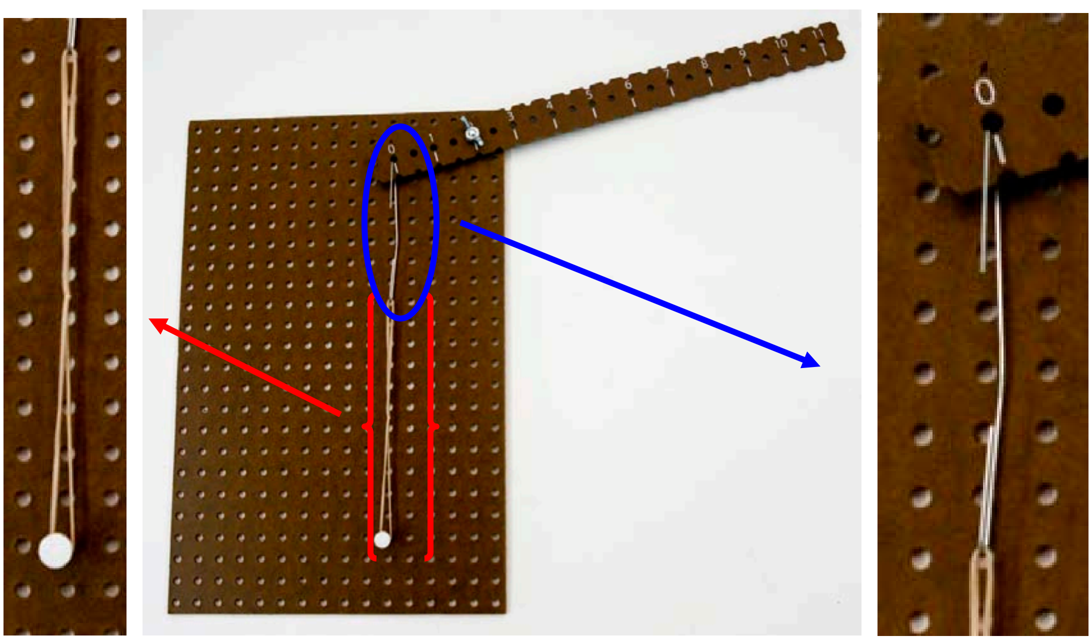



Figure 2 (right): Base with link attached by wing nut; (left) detail of wing nut and lever

2. Straighten a paper clip half way, leaving a loop on each end, and place it through the 0" hole in the link. Loop two #16 rubber bands together. Stretch the rubber bands several times, then hook one end to the bottom of the paper clip in the balance link and the other end around the rivet (See Figure 3).



a) b) c)

Figure 3 (a): Detail of rubber bands, stretching from bottom of paper clip to rivet
(b): Base with lever, paper clip and rubber bands;
(c): Detail of paper clip, attached to link at top and rubber bands at bottom;

Support the base on two wooden stands, as shown in Figure 4.

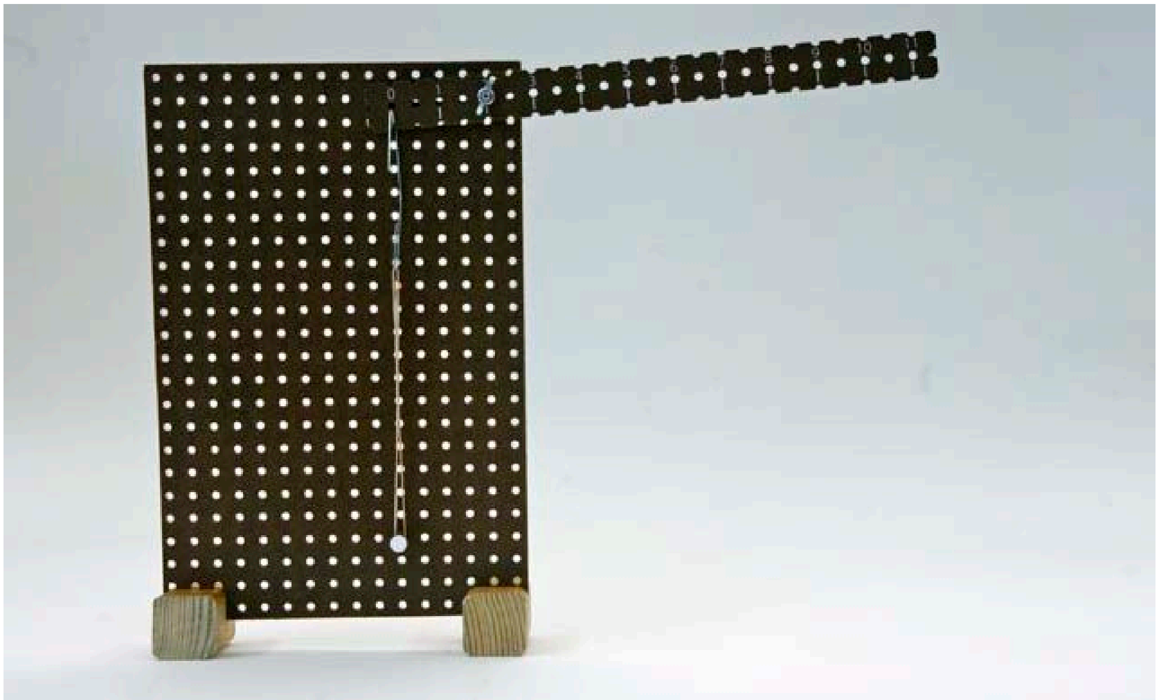


Figure 4: Assembled Force Machine

Analyze the way the Force Machine is constructed. Compare it to the base and lever of Lesson 9. In Lesson 9 the Force Probe had to overcome resistance to move the lever. This resistance was provided by friction between the lever and the fixed pivot and friction between the lever and the base. In the Force Machine the bolt that fastens the screw firmly to the base also keeps the lever from rubbing against the base. The lever fits loosely over the screw (the fixed pivot) so this friction is reduced. The wing nut is not tightened so the lever is gently kept in place. The main force preventing the lever from going down is provided by the rubber bands that pull down on the left side of the lever.

Next, analyze the variables in the Force Machine. The lever of the Force Machine is like a see-saw with the fixed pivot (in simple machine terms, the fixed pivot is the fulcrum) near the left end. There are two force variables and two distance variables.

- The Force Machine uses a rubber band to resist a downward push on the lever.
    - The rubber band pulls down at a distance of 2” from the fixed pivot.
    - The force the rubber band exerts is controlled by always stretching the rubber band the same amount. We do this by always pulling the other end of the lever down the same amount.
    - Thus, we control the variables of force exerted by the rubber band, and the distance from the fixed pivot that its force is exerted.
- The Force Probe is the input to the lever of the Force Machine.
- The two variables associated with the Force Probe are

- the force it exerts on the lever (and the lever opposes in an equal amount), and
- the distance from the fixed pivot that it exerts its force (**input arm**).

This video shows an analysis of the variables in the Force machine. http://citytechnology.org/node/1100.

**Experiment A: Using the Force Machine to measure force**

In Experiment A students compare forces at two distances from the fixed pivot. First distribute the Force Machines or have students assemble them. Next distribute the experiment sheet for Experiment A. It shows the set-up for Experiment A. It is crucial that the hanger clips be hung at the 6" mark (4" from the fixed pivot) and at the 10" mark (8" from the fixed pivot. Let students test the set-up by placing clips at each of the hangers. (See video http://citytechnology.org/node/1122.) Distribute the1" x 12" strips, stands and markers (tape or Post-its).Then introduce the experiment. Here are suggestions for getting students started on Experiment A: http://citytechnology.org/node/1127. A demonstration of carrying out the experiment is provided in this video: http://citytechnology.org/node/1101.

As students carry out the experiment, they will first hang paper clips on the hanger that is 4" from the fixed pivot. They mark on the vertical strip how far down the clips pull the end of the lever. They remove the clips from the 4" hanger and place clips, one-by-one, on the 8" hanger until the end of the lever comes down to the same point on the vertical strip. They should find that it takes half as many clips at the 8" mark as at the 4" mark to pull the lever down to the same point. When students have completed Experiment A, collect the data from all students in a class data table. Consider differences in the results, possible reasons for these differences, and the likely correct results.

Then look for patterns in the data. Here is a video on Experiment A data: http://citytechnology.org/node/1102.

**Outcome**

- For a given number of clips at 4" from the fixed pivot, it takes half as many clips at 8" from the fixed pivot to depress the end of the lever to the same point. It requires half the weights at twice the distance to depress the lever to the same point. This means an equal force is put on the rubber band by 4 clips at 8" from the fixed pivot as by 8 clips at 4" from the fixed pivot. This is a concrete example of the **Law of the Lever**

**Experiment B: Varying the distance and force**

Experiment B allows students to make comparisons among five different lengths of input arms. Students compare the number of paper clips needed at 3", 4", 6", and 8" from the fixed pivot, to stretch the rubber band the same amount as 12 clips at 2" from the fixed pivot.

Introduce students to the set-up and data sheet for Experiment B. Note that hanger clips are placed at the 4", 5", 6", 8" and 10" marks on the lever, resulting in distances from the fixed pivot of 2", 3", 4", 6" and 8". Here are some suggestions. (*http://citytechnology.org/node/1129*.)

A demonstration of doing Experiment B can be seen in this video: *http://citytechnology.org/node/1103*.

Note that this experiment differs from Experiment A in that the lever arm is brought down to the same mark for every trial and this is the same mark that was placed for 12 clips at 2" from the fixed pivot (or fulcrum). When students have completed the experiment, collect the data in a class data table. Consider differences in the results, possible reasons for these differences, and the likely correct results. Then look for patterns in the data. Here is a video on Experiment B data: *http://citytechnology.org/node/1104*.

**Outcome**

The force (in paper clips) x distance from the fixed pivot is a constant, 24 paper clip – inches. The lever was pushed down to the same point by 12 paper clips at 2" from the fixed pivot as by 8 clips at 3", 6 clips at 4", 4 clips at 6" and 3 clips at 8". This is only true when the force and the distance on the other side of the lever remain constant. In Experiment B the rubber band was stretched the same amount (a constant force) and the distance of this force to the fixed pivot, the output arm, was always 2". In this experiment, the **Law of the Lever** may be stated:

The force of the rubber band x the output arm =

The force of the paper clips x the input arm.

**Science Notebook**

- What pattern do you see in the data from Experiment A?
- In Experiment B, how can you get a number that stays the same in each trial, even though the distance and force are both changing? What is the rule
- Test the rule from Experiment B on the data for Experiment A. Does it apply? How can you tell?

**Troubleshooting**

There are several possible sources of inaccurate results. The following sources of inaccurate results are each described in their associated web links.

The lever arm does not move freely: too much friction.

- The wing nut is too tight: http://citytechnology.org/node/1131.
- The hanger clip for the rubber band catches on the base: http://citytechnology.org/node/1132.
- The fixed pivot is loose: http://www.citytechnology.org/node/1128.

Measurement problems

- The length of the input arm is recorded incorrectly: http://citytechnology.org/node/1133

Procedural problems

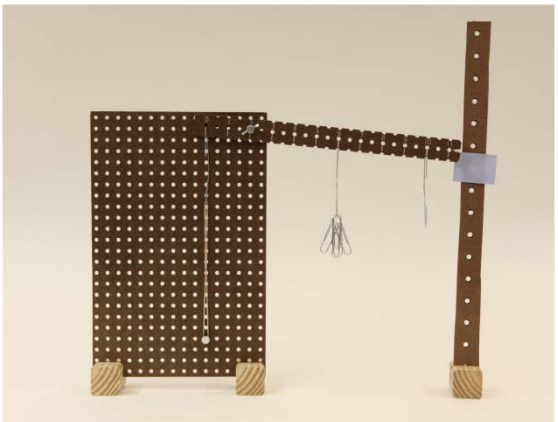
- The marker is not properly set: http://citytechnology.org/node/1134.

Name: ___________________ Date: __________________________

**Force Machine 1: Comparing Weights at 4 ” and 8 ”**
**from the Fixed Pivot (Fulcrum)**

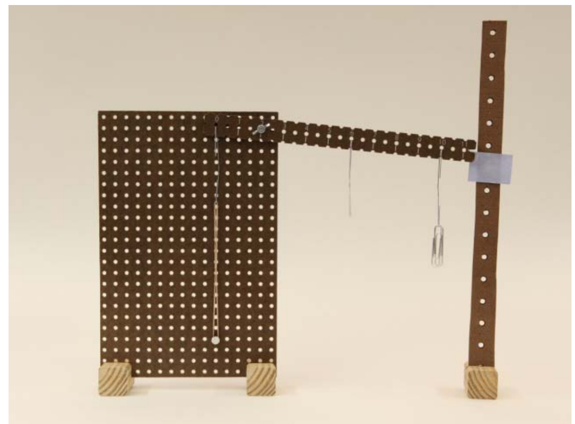
Step 1

Hang clips at 4 ” for Trial 1. Mark the height of the end of the lever.



Step 2

Hang weights at 8 ”. Bring lever down to the mark you set in the first trial. Record # of clips.



| Trial | Distance from fixed pivot | Number of clips on hanger | Distance from fixed pivot | Number of clips including Hanger clip |
|---|---|---|---|---|
| 1 | 4 ” | 2 | 8” | |
| 2 | 4 ” | 4 | 8 | |
| 3 | 4 ” | 6 | 8 | |
| 4 | 4 ” | 8 | 8 | |
| 5 | 4 ” | 10 | 8 | |

What pattern do you see when you compare the number of clips at 4” to the number of clips at 8”?

_________________________________________

___________________________________________________________

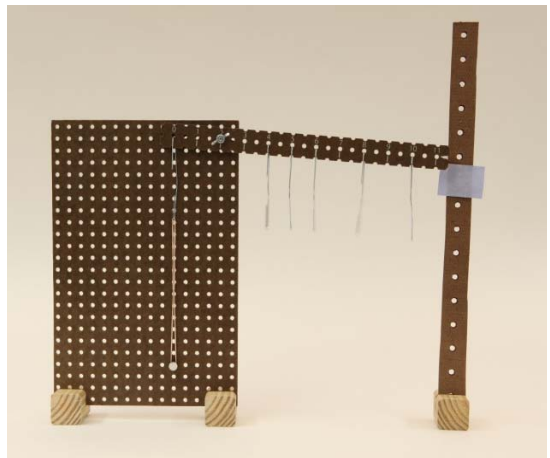
___________________________________________________________

Name: ___________________ Date: __________________________

**Force Machine 2: Weights at Five Distances**

| Input arm length | Hook placement |
|---|---|
| 2” | 4” mark |
| 3” | 5” mark |
| 4” | 6” mark |
| 6” | 8” mark |
| 8” | 10” mark |

Place 12 clips on the hook at the 4” mark, i.e., an input arm of 2”. Place a marker on the stick even with the mark on the end of the lever.



Set-up for Force Machine 2

| Input arm | 2” | 3” | 4” | 6” | 8” |
|---|---|---|---|---|---|
| # of clips | 12 | | | | |

1. Trial 1: The number 12 has already been put in your data table.
2. Trial 2: Take the clips from the hanger at 4” (a 2” input arm) and begin adding them to the hanger at 5” (a 3” input arm) until the lever arm comes down to your marker. Record your data.
3. Trials 3 – 5: Repeat step #2 with the hangers at the 6”, 8”, and 10” marks (input arms at 4”, 6” & 8”). Each time record how many clips are needed to bring the lever to the point you have marked in trial 1.

Describe the pattern you find in how the number of clips changes with the input arm: ____________________________________________

________________________________________________________

***Extension 2: Mechanical Advantage***

***Overview***

In Extension 1 students used the Force Machine to explore the properties of levers and the Law of the Lever. However, students may not realize that they use levers every day. This lesson focuses on a very common lever system – the ordinary pair of scissors, and uses scissors to develop the concept of Mechanical Advantage, which follows directly from the Law of the Lever.

***Materials***

**For the class**

- Chart paper for large drawings of scissors.
- Pegboard model of scissors, made from two links joined with a pivot, and a large pair of scissors.

**For each pair of students**

- A pair of scissors (if possible, there should be a variety of scissor types within the class).
- A ruler graduated in millimeters.
- A small piece of cardboard, thick enough so it is moderately hard to cut.
- Worksheets 1 and 2.

**Procedure**

**Is a scissors a lever?** Demonstrate a pegboard model of a scissors "cutting" something. Then compare this model to real scissors. Elicit the similarities and differences between the pegboard model and the real scissors. Ask why, when we have been studying levers, are we now looking at scissors?

*A scissors is a pair of $1^{st}$ class levers.*

**The scissors problem:** Distribute scissors and small pieces of cardboard. Students try cutting the cardboard at different positions on the blades. They discuss how their findings relate to what was learned with the Force Machine

Moving the cardboard closer to the pivot makes it easier to cut. The scissor blades exert more force close to the fixed pivot.

**Compare scissors to the Force Machine:** Hold scissors next to the Force Machine so the handles compare to the rubber band and the blades compare to the lever. Thus in this comparison the rubber band is taken as providing the input. The output is the force at the different marks on the lever from 4" to 11".

1. *The Scissors and Force Machine are similar:*
    a. *The distance from the rubber band to fixed pivot doesn't change, just like the distance from the scissor handle to the fixed pivot. That is, the input distances remain the same.*
    b. *The output arm and the scissor blade can exert their forces at different distances from the fixed pivot. That is, the output distances can vary.*

c. *Moving the cardboard closer to the pivot makes it easier to cut. The scissor blades exert more force close to the fixed pivot.*

2. *The Scissors and Force Machine are different*

   a. *The Force Machine uses the same input force (a rubber band stretched the same amount.) With scissors we use different input forces.*

**Scissors and the Law of the Lever:** The Law of the Lever states that

input force x input arm = output force x output arm

How does this apply to a pair of scissors?

| | | |
|---|---|---|
| Input force | = | the force you exert on the handles |
| Input arm | = | the distance from where you exert force to the fixed pivot. |
| Output force | = | the force exerted by the scissor blades . |
| Output arm | = | the distance from where blades exert force to the fixed pivot. |

Demonstrate how to measure the input arm (Figure 1) and output arm (Figure 2) of a scissors. In Figure 2 the output is close to the fixed pivot. However, if the scissors are closed a bit, the output is further from the fixed pivot.

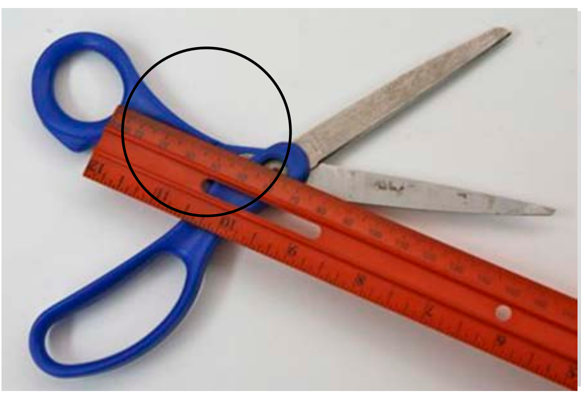


Figure 1: Input arm, from input to fulcrum, is about 60 mm

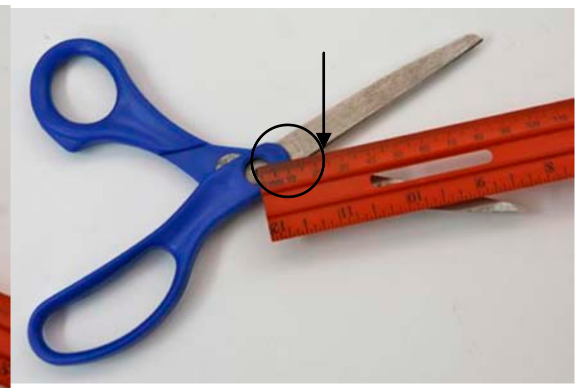


Figure 2: Output arm, from fulcrum to output (marked by arrow) about 25 mm.

The input force and the output force are more difficult to measure. However everyday experience with scissors provides everyone with good qualitative measures.

Show a piece of notebook paper, cardstock, and cardboard.

*Which of these needs more force to cut?*

Demonstrate scissors and cardboard.

*Where should I put the cardboard to cut it?*

*Where do the blades exert the most force?*

How does the Law of the Lever, input force x input arm = output force x output arm, explain this?

The input arm of the scissors is 60mm. Suppose you can squeeze the scissors with 50 pounds of force. Then the input to the scissors is 50 lbs x 60 mm = 3000 lb-mm.

The output has to equal the input: 3000 lb-mm = output force x output arm.

How can the output force be made greater if the output force x output arm will equal 3000 lb-mm?

In discussion help students see that as the output arm changes, the force exerted at the output changes. To make the output force large, the output arm must be small. This is an application of the Law of the Lever. Thus

> *The Law of the Lever explains why cutting is easier close to the pivot and more difficult far from the pivot.*

**What is Mechanical Advantage?** The ratio of (input arm) / (output arm) is useful in telling you how easy or hard it will be to use a lever. This ratio is called **Mechanical Advantage**. With scissors the Mechanical Advantage is made big by cutting closer to the fixed pivot. The ratio of (input arm) / (output arm) becomes larger when the output arm becomes smaller. When cutting close to the end of the scissors, the output arm is long and the ratio of (input arm) / (output arm) becomes smaller.

***Mechanical Advantage = (Input arm) / (Output arm).***

**Mechanical Advantage for a scissors used two ways:** Distribute worksheets 1. Scissors with output near fulcrum and 2. Scissors with Output far from Fulcrum. Review the instructions on the worksheets. Students measure and record the length of the input arm and the output arm when cutting close to the pivot (Worksheet 1) and when cutting far from the pivot (Worksheet 2). They calculate the Mechanical Advantage of the scissors when cutting at each of the positions, using the lengths of the input arm and output arm. The ratio (input arm) / (output arm) is important, because it also tells you the ratio between the force you supply at the input, and how much force comes out at the output.

**Discussion of data from scissors measurements.** Students compare the Mechanical advantages they calculated for different scissors and different points of cutting.

**Further investigations of Mechanical Advantage.** Students measure other everyday mechanisms and calculate their Mechanical Advantages. Especially interesting are tools with long handles such as bolt cutters, pliers, wrecking bars and lopping shears.

**Outcomes**

In this lesson students learn to:

- Recognize levers in everyday tools and utensils
- Measure input arm and output arm
- Refer to the fixed pivot of an everyday mechanism as a fulcrum.

They should develop the following concepts:

- The ratio of (input arm) / (output arm) is called Mechanical Advantage. It lets you predict how easy or hard it will be to use a lever.
- To get the same job done, you will need to supply more force to a lever that has a low Mechanical Advantage than to a similar lever with high Mechanical Advantage.
- You can increase the Mechanical Advantage by reducing the output arm (distance from the fulcrum to the output).

- You can increase the Mechanical Advantage by increasing the input arm (distance from the input to the fulcrum). This applies to mechanisms that can be grasped at different places.

Name: ___________________ Date: __________________________

1. Scissors with output near fulcrum

| In the box, draw your scissors with the cardboard near the pivot (fulcrum) – scissors nearly open: |
|---|
| |
| |

1. In your drawing, label the
   - ✂ input (this is where you hold the scissors),
   - ✂ output (this is where you place the paper)
   - ✂ fulcrum or pivot
2. On your scissors, measure and record the distances in millimeters between
   - ✂ input arm (distance from input to fulcrum) _________
   - ✂ output arm (distance the fulcrum to output) _______
3. Find the ratio (input arm) / (output arm) ________
4. What happens when you try to cut with a scissors this way?

___________________________________________________

Name: ___________________ Date: __________________________

2. Scissors with Output far from Fulcrum

| In the box below, draw your scissors with the cardboard near the end – scissors almost closed: |
|---|
| |

1. In your drawing, label the
   - ✁ input (this is where you hold the scissors),
   - ✁ output (this is where you place the paper)
   - ✁ fulcrum or pivot
2. On your scissors, measure and record the distances in millimeters between
   - ✁ input arm (distance from input to fulcrum) ________
   - ✁ output arm (distance the fulcrum to output) _______
3. Find the ratio (input arm) / (output arm) __________
4. What happens when you try to cut with a scissors this way?

___________________________________________________

*Troubleshooting*

**Measuring distances.** On many scissors the end of the pivot is several mm wide. From where on the pivot end should measurements be made? The scissors rotate around a point that is at the very center of the end of the pivot. Therefore, make measurements from the center.