Bell Ringer: First-Class Levers – ID: 13441

Based on an activity by Irina Lyublinskaya

Time required
15 minutes

Topic: Force and Motion

- *Predict and describe the effect of balanced forces on an object.*
- *Describe the relationship between torque, force, and lever arm.*

Activity Overview

In this activity, students explore the conditions necessary to produce static equilibrium in a first-class lever. They will examine data on the force necessary to achieve static equilibrium for levers with different effort arms. They will use these data to determine the relationship between torque, force, and effort arm for the lever.

Materials

To complete this activity, each student or student group will require the following:

- *TI-Nspire™ technology*
- *pen or pencil*
- *blank paper*

TI-Nspire Applications

Graphs & Geometry, Notes, List & Spreadsheet

Teacher Preparation

Before carrying out this activity, students should be familiar with the concept of static equilibrium and the definition of torque. You should also review the conditions necessary for static equilibrium (i.e., $\vec{\tau}_{net} = 0$ and $\vec{F}_{net} = 0$) and the definition of a first-class lever.

- *The screenshots on pages 2–5 demonstrate expected student results. Refer to the screenshots on page 6 for a preview of the student TI-Nspire document (.tns file). The solution .tns file contains a data analysis and answers to the questions.*

- ***To download the student .tns file, solution .tns file, and sample data set, go to education.ti.com/exchange and enter "13441" in the search box.***

- *For a more extensive exploration of this content, use activity 11265: Balancing Torques and Forces. Activity 11265, which is longer than this bell ringer and involves data collection and analysis by the students, was designed for a full-length class period. You can download the files for activity 11265 at education.ti.com/exchange.*

Classroom Management

- *This activity is designed to be **student-centered**, with the students working cooperatively. However, you will need to guide students through the steps of the activity.*

- *If you wish, you may modify this document for use as a student worksheet. You may also wish to use an overhead projector and TI-Nspire computer software to demonstrate the use of the TI-Nspire to students.*

- *If students do not have sufficient time to complete the questions, they may also be completed as homework.*

- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:
- What is the relationship between effort force and resistance force when a lever is balanced?
- What is the relationship between effort torque and resistance torque when a lever is balanced?
- What is the relationship between the magnitude of the effort force and the lever arm when a lever is balanced?

The goals of this activity for students are a) to observe and compare the effort force and torque needed to maintain the balance of a lever when the position of the effort force is varied, b) to determine what factors affect static equilibrium, and c) to determine whether there is a correlation between the magnitude of the effort force and its lever arm when static equilibrium is maintained. Students use precompiled data on effort force and lever arm, analyze these data, calculate the net force and the net torque on the system, and determine whether there is a correlation between the effort force and the lever arm when static equilibrium is maintained.

Step 1: Students should open the file **PhysBR_week10_1stclass_lever.tns** and read the first two pages. (Students can press $\boxed{\text{ctrl}}\blacktriangleright$ and $\boxed{\text{ctrl}}\blacktriangleleft$ to move between pages in the .tns file.) They should then move to page 1.3 and answer question 1. Question 1 asks students to draw a force diagram for the lever shown on page 1.2. Students can either draw the diagram on a blank piece of paper or use the **Segment**, **Vector**, and **Triangle** tools to construct the diagram in the *Graphs & Geometry* application on the bottom half of page 1.3. To switch to the *Graphs & Geometry* application, students should press $\boxed{\text{ctrl}}\boxed{\text{tab}}$. The **Segment** and **Vector** tools are accessible from the **Points & Lines** menu (**Menu > Points & Lines**), and the **Triangle** tool is accessible from the **Shapes** menu (**Menu > Shapes**).
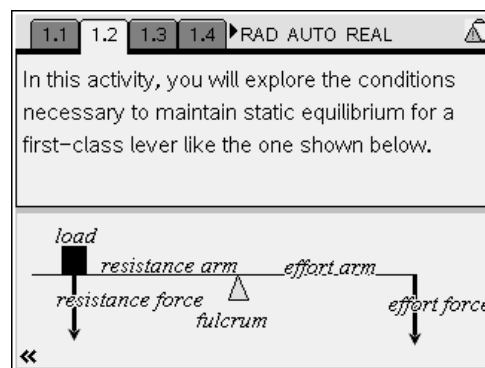
Q1. Draw a force diagram for the first-class lever shown on the previous page. Draw the diagram in the *Graphs & Geometry* application below or on a blank piece of paper.

A. *A sample force diagram is shown below.*

Load

N

F_r Fulcrum F_e
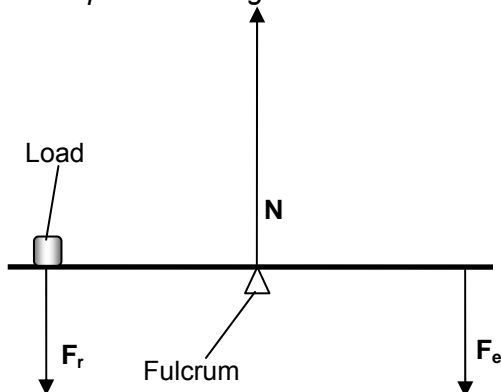
Here N *is the normal force,* F_r *is the resistance force (and is equal to* W*, the weight of the load), and* F_e *is the effort force.*

Step 2: Students should read the text on page 1.4, which describes how the sample data in this activity were collected. They should then move to page 1.5, which shows a graph of effort force vs. effort arm length for a first-class lever. The data on this page were collected for a lever set up as shown to the right.
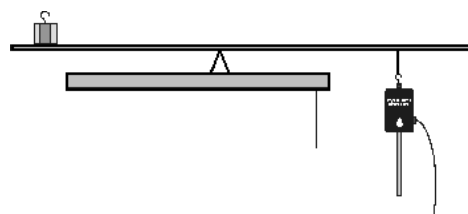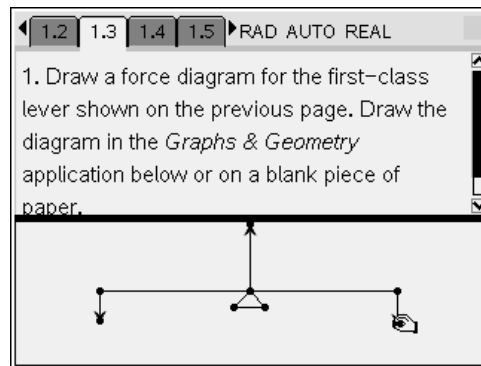
Step 3: Students should study the data on page 1.5 and then answer question 2.

Q2. What happens to the effort force as the length of the effort arm decreases?

A. *The effort force increased as the effort arm became shorter. The closer to the fulcrum the effort force is applied, the larger the force that is necessary to balance the resistance force.*
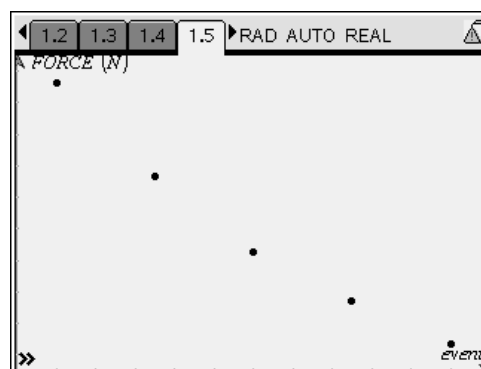
Step 4: Next, students should move to page 1.7, which shows a *Lists & Spreadsheet* application containing the data collected for the experiment. The length of the effort arm, **e_arm**, is shown in column A. The magnitude of the effort force, **e_force**, is shown in column B. Students should calculate the effort torque in column C and label the series **e_torque**. To label the series, students should type *e_torque* into the label cell in column C. (Students can type an underscore by pressing (ctrl)(⊖). They can use the NavPad to move between cells.) They should press (enter) to move to the formula bar. They should then enter the expression **=a[]·b[]** in the formula bar for column C and press (enter). (To enter the brackets, students should press (ctrl)(⊓) and then press ▸ on the NavPad to exit the bracket.) Column C should now display the effort torque for each trial. Students should study the data and then answer questions 3–6.

e_arm	e_force	e_torque	D
=dc01.even	=dc01.force		
0.4	4.66216		
0.35	5.36199		
0.3	6.14182		
0.25	7.34297		
0.2	8.82301		

C *e_torque*

e_arm	e_force	e_torque	D
=dc01.even	=dc01.force	a[ ]·b[ ]	
0.4	4.66216		
0.35	5.36199		
0.3	6.14182		
0.25	7.34297		
0.2	8.82301		

C **e_torque:**=a[ ]·b[ ]

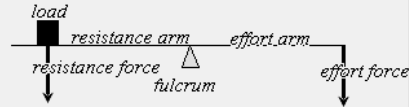| e_arm	e_force	e_torque	D
=dc01.even	=dc01.force	=a[]*b[]	
0.4	4.66216	1.86486	
0.35	5.36199	1.8767	
0.3	6.14182	1.84255	
0.25	7.34297	1.83574	
0.2	8.82301	1.7646	

C1 =1.864864

Q3. The load used in this experiment had a weight of 4.5 N. It was placed 0.4 m from the fulcrum. Calculate the torque produced by the resistance force (load) for all trials.

A. *The resistance torque (τ_r) is equal to the product of the resistance force and the resistance arm. Therefore, it is equal to 4.5 N × 0.4 m = 1.8 N·m.*

Q4. The effort force produces a torque on the lever. What happens to the magnitude of that torque as the position where the effort force is applied varies? Explain your answer.

A. *Students should study the torque values they calculated in step 4. They should observe that the magnitude of the effort torque (τ_e) is relatively constant and is approximately equal to the resistance torque. They should use theoretical considerations to explain this observation. At static equilibrium, there is no net torque on the lever. In other words, $\tau_e - \tau_r = F_e d_e - F_r d_r = 0$.*
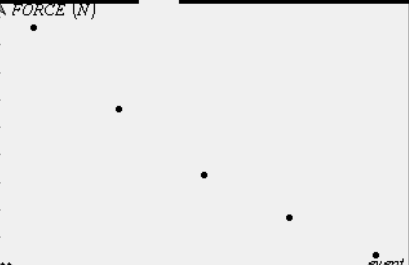
Q5. What type of mathematical equation represents the relationship between the length of the effort arm and the magnitude of the effort force?

A. *There is an inverse relationship between the effort force and the length of the effort arm:*

$F_e = \dfrac{k}{d_e}$. *This is the equation of a hyperbola. If time allows, you can have students*

*change the graph on page 1.3 to a **Function** graph (**Menu > Graph Type > Function**) and graph the formula for a hyperbola. They can use the average value of the variable **torque** as the constant in the equation. The resulting curve should fit the sample data quite well.*

Q6. How could this relationship between effort force and lever arm be used to reduce the effort required to lift a heavy load with a first-class lever?

A. *By moving the fulcrum closer to the load and making the effort lever arm longer, you can make the effort force smaller than the resistance force. This is the principle behind how the first-class lever works.*

Suggestions for Extension Activities: If you wish, you may have students use a Vernier Dual-Range Force sensor and EasyLink™or Go!® Link interface to collect their own force data.

Bell Ringer: First-Class Levers – ID: 13441

(Student)TI-Nspire File: *PhysBR_week10_1stclass_lever.tns*

1.1 1.2 1.3 1.4 ▸RAD AUTO REAL △ **FIRST-CLASS LEVERS** **Physics** Statics	1.1 **1.2** 1.3 1.4 ▸RAD AUTO REAL △ In this activity, you will explore the conditions necessary to maintain static equilibrium for a first-class lever like the one shown below. *load* ▬ *resistance arm* *effort arm* *resistance force* △ *effort force* *fulcrum* «	1.1 1.2 **1.3** 1.4 ▸RAD AUTO REAL △ 1. Draw a force diagram for the first-class lever shown on the previous page. Draw the diagram in the *Graphs & Geometry* application below or on a blank piece of paper. «
1.1 1.2 1.3 **1.4** ▸RAD AUTO REAL △ The data on the next page were collected using a force sensor. A load was placed on one side of the lever. The force required to balance the lever was measured. Then, the length of the effort arm was changed (the resistance arm length remained constant). The force required to balance the lever for different effort arm lengths was recorded. The graph shows the data values.	◂ 1.2 1.3 1.4 **1.5** ▸RAD AUTO REAL △ *FORCE (N)* • • • • • *event* »	◂ 1.3 1.4 1.5 **1.6** ▸RAD AUTO REAL 2. What happens to the effort force as the length of the effort arm decreased?
◂ 1.4 1.5 1.6 **1.7** ▸RAD AUTO REAL △ A e_arm / B e_force / C / D ◆ =dc01.even =dc01.force 1 │ 0.4 │ 4.66216 2 │ 0.35 │ 5.36199 3 │ 0.3 │ 6.14182 4 │ 0.25 │ 7.34297 5 │ 0.2 │ 8.82301 *A1* │ =0.4	◂ 1.5 1.6 1.7 **1.8** ▸RAD AUTO REAL 3. The load used in this experiment had a weight of 4.5 N. It was placed 0.4 m from the fulcrum. Calculate the torque produced by the resistance force (load) for all trials.	◂ 1.6 1.7 1.8 **1.9** ▸RAD AUTO REAL 4. The effort force produces a torque on the lever. What happens to the magnitude of that torque as the position where the effort force is applied varies? Explain your answer.
◂ 1.7 1.8 1.9 **1.10** ▸RAD AUTO REAL 5. What type of mathematical equation represents the relationship between the length of the effort arm and the magnitude of the effort force?	◂ 1.8 1.9 1.10 **1.11** RAD AUTO REAL 6. How could this relationship between effort force and lever arm be used to reduce the effort required to lift a heavy load with a first-class lever?	