Science Objectives

- Students will predict and describe the effect of balanced forces on an object.
- Students will measure or calculate the net force on an object.
- Students will describe the relationship between torque, force, and lever arm.

Vocabulary

- effort arm
- first-class lever
- fulcrum
- resistance arm
- second-class lever
- static equilibrium
- third-class lever
- torque

About the Lesson

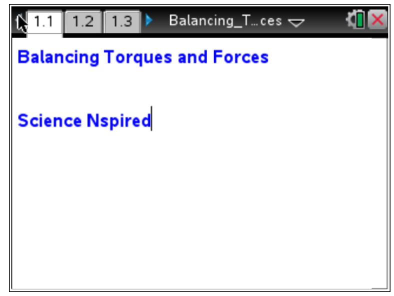
- In this activity, students explore the conditions necessary to produce static equilibrium using first-, second-, and third-class levers.
- As a result, students will:
    - Change the length of the effort arm for each lever and measure the force necessary to achieve static equilibrium.
    - Use these data to determine the relationships between torque, force, and effort arm for the different levers.

TI-Nspire™ Navigator™

- Send out the *Balancing_Torques_and_Forces.tns* file.
- Monitor student progress using Screen Capture.
- Use Live Presenter to spotlight student answers.

Activity Materials

- *Balancing_Torques_and_Forces.tns* document
- TI-Nspire™ Technology
- Vernier Dual-Range Force sensor
- Vernier EasyLink™ or Go!® Link interface
- mass (at least 200 g)
- meterstick
- fulcrum (e.g., small square dowel)
- string
- level



TI-Nspire™ Technology Skills:

- Download a TI-Nspire document
- Open a document
- Move between pages

Tech Tip:

Access free tutorials at http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials

Lesson Files:

Student Activity

- Balancing_Torques_and_Forces_Student.doc
- Balancing_Torques_and_Forces_Student.pdf

TI-Nspire document

- Balancing_Torques_and_Forces.tns

Activity Overview

- This is a student-centered activity, with the teacher acting as a facilitator while students work cooperatively.
- Please print the student worksheet and make available to students before beginning the lab. Lab background as well as lab procedure are included in the student worksheet.
- Student will calculate torques in the .tns file and otherwise will answer questions directly on the student activity sheet.
- Ensure that students collect data for the three sections of the lab.

TI-Nspire Navigator Opportunities

Use the TI-Nspire Navigator System to monitor students' calculations of torques. You may also circulate around the room to guide them in this step.

Discussion Points and Possible Answers

Lab Set-Up and Procedures

Please note that detailed lab procedures are outlined in the student activity sheet. A summary of the Problem 1 procedure is included here for convenience. Students will repeat essentially the same procedure in each problem.

Pre-lab Information and Questions

Have students answer the pre-lab questions prior to starting the lab procedure in each problem.

Problem 1: First-Class Levers

Move to page 1.2.

Have students answer the questions on the activity sheet.

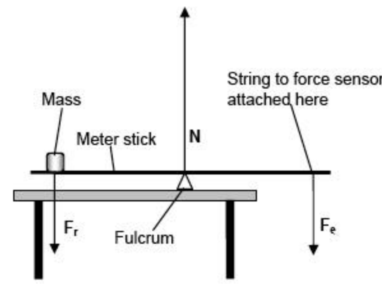
1. Students set up a lever using a fulcrum and meterstick. They set the switch on the force sensor is in the ±10 N position. They connect the force sensor to the EasyLink interface (if using handheld) or to the Go! Link (if using computer), but do not connect to the handheld or computer yet.

Q1. If you place a mass at the 90-cm mark on the meterstick, where do you think you would need to apply a larger force to balance the meterstick—at the 10-cm mark or at the 40-cm mark? Assume that the fulcrum is at the 50-cm mark.

Answer: The force needed to balance the mass is larger when applied at the 40-cm mark, because the 40-cm mark is closer to the fulcrum (and the force therefore has a smaller lever arm).

Q2. What forces act on the system in static equilibrium? Draw a force diagram.

Answer: A sample force diagram is shown at right. Here *N* is the normal force, F_r is the resistance force (and is equal to *W*, the weight of the mass), and F_e is the effort force.



Problem 1: Lab Set-Up and Procedures

Move to page 1.3.

2. Students will use a Vernier Dual-Range Force sensor to collect force data.
3. Students select **Menu > Experiment > View > Graph** so data will be displayed in the graph view.
4. Students zero the force sensor (**Menu > Experiment > Set up Sensors > Zero**), then hang the mass from the sensor with a string loop. They record the reading (to the nearest 0.1 N) as the resistance force.
5. Students remove the mass from the force sensor and zero the sensor (after the reading stabilizes).
6. Students set up data collection (**Menu > Experiment > Collection Mode > Events with Entry**).
7. Students place the mass on the meterstick, centered on the 90-cm mark. They loop the string over the meterstick at the 10-cm mark.
8. Students click on **Start** and pull down on the force sensor until the meterstick is horizontal (using the level to check). They click on **Keep** to save the data point. In the event box, they enter the distance (in meters) between the fulcrum and the string.
9. Students repeat Step 8 at least four times, moving the string 5 cm closer to the fulcrum for each trial. Once the data have been collected, they disconnect the sensor.

Have students answer the questions on the activity sheet.

Q3. What was the length of the resistance arm (the lever arm of the resistance force) in each trial?

Answer: The resistance force (F_r) is the weight of the 200 g mass, and the resistance arm (d_r) is the distance from the fulcrum to the point where the resistance force is applied. If the fulcrum is at the 50-cm mark and the mass is placed at the 90-cm mark, the resistance arm is 0.9 m – 0.5 m = 0.4 m. Because the mass remained in the same location throughout the experiment, the resistance arm was the same in all trials.

Q4. What was the length of the effort arm (the lever arm of the effort force) in each trial?

Answer: The effort force (F_e) is the downward force applied by pulling on the force sensor, and the effort arm (d_e) is the distance from the fulcrum to the point where that force is applied. The effort arm for each trial is the value students entered as the event value for that trial.

Q5. What happened to the effort force as you decreased the length of the effort arm?

Answer: 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.

Move to page 1.4.

10. They set column A to display *run1.event* and column B to display *run1.force* (the effort force data students collected). They label column A “e_arm” and column B “e_force.”
11. Students enter =a[ ] • b[ ] in the formula bar for column C and label column C “torque.”

Have students answer the questions on the activity sheet.

Q6. The effort force produces a torque on the lever. What happens to the magnitude of that torque as you change the position where the effort force is applied? Explain your answer.

Answer: Students should study the torque values they calculated in step 14. They should observe that the magnitude of the effort torque (T_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, $T_e - T_r = F_e d - F_r d_r = 0$.

Q7. What type of mathematical equation represents the relationship between the length of the effort arm and the magnitude of the effort force?

Answer: There is an inverse relationship between the effort force and the length of the effort arm: $F_e = k/d_e$. 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.

Q8. 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?

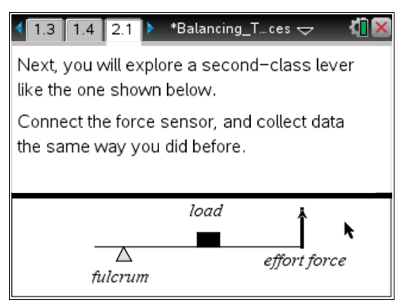
Answer: By moving the fulcrum closer to the load and making the effort lever arm longer, you can make the effort force smaller than the resistance force. This is the principle of how the first-class lever works.

Problem 2: Second-Class Levers

Move to page 2.1.

Have students answer the questions on the activity sheet.

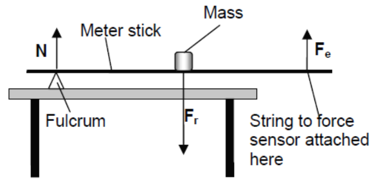
12. Students place the fulcrum in the middle of the table, and place the meterstick on top of it so that fulcrum is aligned with the 90-cm mark on the meterstick.



Q9. How is the second-class lever different from the first-class lever?

Answer: In the second-class lever, the resistance force is between the effort force and fulcrum. In a first-class lever, the fulcrum is between the effort force and the resistance force. In a second-class lever, the effort force is applied in the direction opposite to the direction of the resistance force. In a first-class lever, the effort force and the resistance force act in the same way.

Q10. What forces act on this system in static equilibrium? Draw a force diagram.



Answer: A sample force diagram for a second-class lever is shown at the right.

Q11. At what position do you think the effort force is minimal? Explain your answer.

Answer: The effort is minimal at the farthest point from the fulcrum (the 0-cm mark, in this case). Students should reason that, at equilibrium, the effort torque is equal to the resistance torque. As the length of the effort arm increases, the required effort force decreases. Therefore, to make the required effort force as small as possible, the effort arm should be made as large as possible.

Problem 2: Lab Set-Up and Procedures

Move to page 2.2.

Have students read Steps 13–19 and answer the questions on the activity sheet.

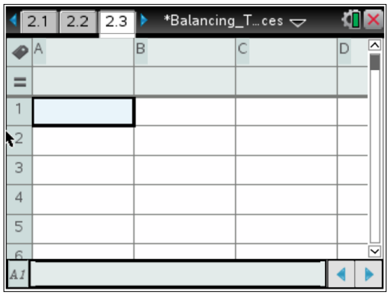
Q12. What were the initial lengths of the effort and resistance arms?

Answer: The initial resistance arm is the distance from the fulcrum to the point where the load is applied, so it is equal to 0.9 m – 0.5 m = 0.4 m. The initial effort arm is the distance from the fulcrum to the point where the string was first attached, so it is equal to 0.9 m – 0.1 m = 0.8 m.

Q13. What happened to the effort force as you decreased the length of the effort arm?

Answer: As the effort arm became shorter, the effort force increased in magnitude. The closer to the fulcrum the force is applied; the harder it is to balance the weight. This is similar to the situation with the first-class lever.

Move to page 2.3.



20. Students calculate the torque produced by the resistance force (load) for all trials. Sample data is shown at the right.
21. Students label column C “torque.” Students enter the expression =a[ ] • b [ ] in the formula bar for column C and press **enter**.

Have students answer the questions on the activity sheet.

Q14. What happens to the effort torque as you change the position where the effort force is applied? Explain your answer.

Answer: Students should study the torque values they calculated. They should observe that the magnitude of the effort torque (T_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, $T_e - T_r = F_e d_e - F_r d_r = 0$.

Q15. Give a real-world example of a second-class lever.

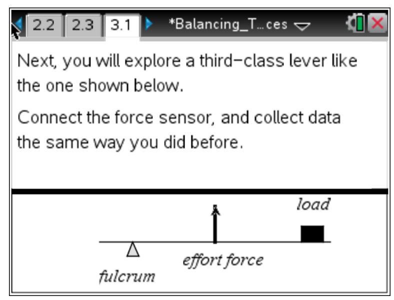
Answer: Answers will vary.

Q16. In a second-class lever, where should the load be placed to minimize the effort force?

Answer: Answers will vary.

Problem 3: Third-Class Levers

Move to page 3.1.



Have students answer the questions on the activity sheet.

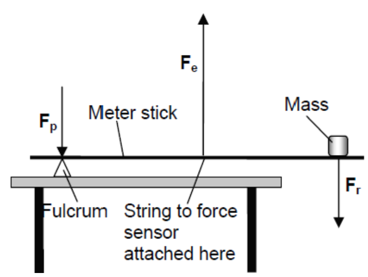
22. In this part of the activity, leave the meterstick and fulcrum in the same positions as they were in for Problem 2 (the fulcrum at the 90-cm mark on the meterstick). Remove the mass from the meterstick.

Q17. Is it possible to balance a third-class lever with an effort force that is smaller than the resistance force? Explain your answer.

Answer: In a third-class lever at static equilibrium, the effort force must be greater than the resistance force because the effort arm must be shorter than the resistance arm.

Q18. What forces act on the system in static equilibrium? Draw a force diagram.

Answer: A sample force diagram is shown at right. Here, F_p is the force that must be applied to the lever at the fulcrum in order to allow rotation rather than lifting of the lever.



Q19. What is a common third-class lever you use every day?

Answer: When a person lifts an object by bending his or her arm at the elbow while keeping the upper arm rigid (i.e., doing a biceps curl), the forearm is acting as a third-class lever. The elbow is the fulcrum. The weight of the object being lifted (which is held in the hand) is the resistance force. The effort force is supplied by the biceps muscle, which attaches from the upper arm to the bones of the forearm between the elbow and the wrist.

Problem 3: Lab Set-Up and Procedures

Move to page 3.2.

Have students read Steps 23–29 and answer the questions on the activity sheet.

Q20. What were the initial lengths of the effort arm and the resistance arm?

Answer: Answers will vary.

Q21. What happened to the effort force as you increased the length of the effort arm?

Answer: As the effort arm became longer, the e force decreased. The greater the distance between the fulcrum and the effort force the less force is needed to balance the weigh however, the magnitude of the effort for always larger than the magnitude of the resistance force.

Move to page 3.3.

Have students read Steps 30–31 and answer the questions on the activity sheet.

Q22. What happens to the effort torque as you change the position where force is applied? Explain your answer.

Answer: Students should study the torque values they calculated in procedure 10 of Problem 3. They should observe that the magnitude of the effort torque (T_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 not net torque on the lever. In other words, $T_e - T_r = F_e d - F_r d_r = 0$.

Q23. Why do we use third-class levers if they do not reduce the required effort force?

Answer: Answers will vary.

TI-Nspire Navigator Opportunity

Use the Ti-Nspire Navigator System to collect, grade, and save the .tns file to the Portfolio. Use Slide Show to view student responses.

Wrap Up

When students are finished with the activity, pull back the .tns file using TI-Nspire Navigator. Save grades to Portfolio. Discuss activity questions using Slide Show.

Upon completion of the lab and discussion, the teacher should ensure that students are able to understand:

- the three classes of levers, equilibrium and torque
- the relationship between them
- the importance of data collection and analysis

Assessment

- Formative assessment will consist of questions embedded in the .tns file. The questions will be graded when the .tns file is retrieved by TI-Nspire Navigator. The TI-Nspire Navigator Slide Show can be utilized to give students immediate feedback on their assessment.
- Summative assessment will consist of questions/problems on the chapter test, inquiry project, performance assessment, or an application/elaborate activity.