LEVERS AND MECHANICAL ADVANTAGE

INTRODUCTION

This lesson is part of a unit on work, power, and machines. Within this lesson, students will be introduced to the basic principles of machines, and review the six simple machines. In the lab activity, students will use a first class lever to explore the relationship between fulcrum position and effort force required to operate the lever. Students will analyze their experimental data both quantitatively, by calculating ideal and actual mechanical advantage, and qualitatively, by summarizing their results. Following the experiment, students will complete five guided practice problems to practice mechanical advantage calculations.

As part of their summative assessment on this unit, students will play a review game, which incorporates ideal and actual mechanical advantage calculations with work, power, and efficiency calculations, and then take a test on these concepts.

LEARNING OUTCOMES

- During this lesson, students will learn the six simple machines. Using 1st class levers of their own construction, they will calculate mechanical advantage of their levers by measuring effort and resistance distances, and force. Students will generate their own procedure for collecting experimental data.
- As a result of this lesson, students will be able to calculate mechanical advantage and ideal fulcrum position for lever scenarios in word problems. Students will also be able to determine effort and resistance distances for levers in order to calculate mechanical advantage.

CURRICULUM ALIGNMENT:

NEXT GENERATION SCIENCE STANDARDS: *FRAMEWORK FOR K-12 SCIENCE EDUCATION*

Dimension 1: Scientific and Engineering Practices

Practice 2 Developing and using models to explore a concept, collect data, and draw conclusions.

Dimension 2: Crosscutting Concepts

2. Cause and effect: Mechanism and explanation.
6. Structure and function.

Dimension 3, Core Idea PS3: Energy

PS3.C Relationship between energy and forces

NORTH CAROLINA ESSENTIAL STANDARDS – PHYSICAL SCIENCE

PSc.3.1 Understand the types of energy, conservation of energy and energy transfer.

PSc.3.1.4 Explain the relationship among work, power and simple machines both qualitatively and quantitatively.

NORTH CAROLINA ESSENTIAL STANDARDS – PHYSICS

Phy.2.1 Understand the concepts of work, energy, and power, as well as the relationship among them.

Phy.2.1.3 Explain the relationship among work, power and energy.

NORTH CAROLINA VOCATS COURSE BLUEPRINTS – PRINCIPLES OF TECHNOLOGY I

001.00 Analyze and apply the concept of forces in mechanical systems.

001.02 Use laboratory equipment to solve mechanical problems.

005.00 Analyze and apply the concept of work in mechanical systems.

005.02 Use laboratory equipment to solve mechanical work problems.

CLASSROOM TIME REQUIRED

Three 90-minute block periods

TEACHER PREPARATION

Before the lesson, organize the students into pairs. Place the lab materials at stations throughout the room. Make copies of lab handouts and guided practice problems for all students. Review the presentation on machines and levers and make any necessary modifications to meet your needs. Attempt the lab and review guided practice problems on your own to prepare yourself for any complications or questions that might arise during the lesson.

Around the World Review Game Preparation

- Print the problems from the PowerPoint file, one per page.
- Print a cover sheet with a country on it for each problem from AroundTheWorld_CoverSheets.doc.
- Color the country or label the country with a color on each cover sheet, then attach one cover sheet to each problem so that students will be able to flip the cover sheet up and read the problem underneath.
- Post the 14 problems around the classroom so that students can find each one as they play the game.
- Print a world map for each pair of students.
- Place students in new pairings.
- Attempt each calculation on your own first to generate an answer key and to be prepared for any questions students may ask.

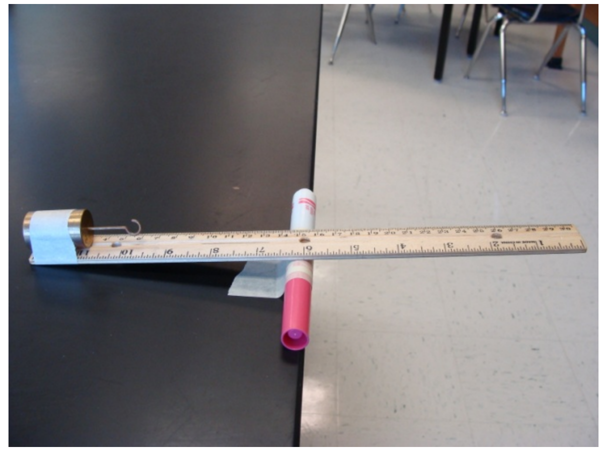
MATERIALS NEEDED

For each student:

- Sheet of paper
- Lab handout
- Pencil
- Calculator

For each lab station:

- 12-in ruler (wood works best)
- "fat" Crayola-type marker
- 2 strips of masking tape (one for taping down the marker to the lab bench, one for taping the mass to the ruler)
- 100-g mass (ideal, but can work with slightly less or slightly more)
- Spring scale



To the right is a photo for the uniform lever students will assemble.

TECHNOLOGY RESOURCES

- Computer
- Projector
- PowerPoint presentation
- Calculators

PRE-ACTIVITIES

REVIEW

This lesson on levers is designed as part of a unit on *work*, *power*, and *machines*. Prior to this lesson, students should have been instructed on

- The relationship between work and power and calculations involving both of these,
- Friction and how it reduces efficiency in all systems, and
- The concept of force, how to calculate it, and the units in which it is measured.

The teacher may wish to have a brief class discussion before this lesson to review these key points.

INTRODUCE

Use the lesson presentation to introduce the concept of machines. Students should jot down any unfamiliar information in their notebooks.

EXPLORE MACHINES

- Send the groups of students to the lab stations.
- Challenge each group to use the materials given to make three different machines, which will lift the mass. Note that students should not catapult the mass across the room.
- Have students sketch and label all three machines on their piece of paper.
- Take a few minutes for groups to share their best machine with the class in a gallery walk.

ACTIVITIES

Using the lesson presentation, instruct students on the six types of simple machines. Teach them the basic parts and functions of machines, and how to determine those on a lever. Pass out the lab data sheets.

MODEL SYSTEM

Guide students in constructing a uniform 1^{st} class lever according to the photo provided above, and the following directions:

- Tape a marker on the edge of a table or lab bench as a fulcrum.
- Place the lever (ruler) on top of the fulcrum with the smaller numbers resting on the table and the larger numbers oriented off the table.
- Place the 100-g mass (the load) on the edge of the ruler resting on the table.
- Use the ruler edge that is off the table to connect the spring scale for applying and measuring the effort force.

EXPLORATION

Students will explore the relationship between the effort force and the resistance distance by modifying their lever in three ways of their choosing. Before beginning, have students predict what they will observe about this relationship on the *Hypothesis* section of their data sheet.

Have students use a spring scale to measure the force required to lift the 100-g load to the height of the marker without using a lever. They will record and label this as the "resistance force" on their data sheets.

For the first fulcrum position, students should pick a location on the ruler (noted by the cm or mm marking) to position the fulcrum and record the location on their data sheets in the *Experimental Setup* section and in the caption for *Data Table 1*. They must record the effort and resistance distances in Data Table 1.

The effort distance is the length from the end of the ruler where the effort was applied to the fulcrum (*total length of ruler – fulcrum position).* The resistance length is the distance from the beginning of the ruler to the fulcrum (*equal to the fulcrum position*). Students will then record the *effort force* needed to "level" the ruler over three trials (level is measured by the height of the *load* to the height of the marker), and average this force for the three trials.

This process will be repeated with two additional *fulcrum* positions (total of 3 positions with 3 trials each).

CONTENT WRAP-UP

Students should return to their seats with their data. Introduce the concept of *mechanical advantage* and show equations for calculating ideal and actual mechanical advantage. Students then analyze their own experimental data by calculating ideal (IMA) and actual (AMA) mechanical advantage on their data sheets. Each fulcrum position will have its own *IMA* and *AMA*.

Findings of the relationship between the effort force and the resistance distance are summarized in paragraph form on the data sheet. Data and calculations are discussed, as is validity of the hypothesis.

Have the students turn in the lab sheets for review. As a class discuss the overall findings of the relationship between the effort force and the resistance distance. The consensus should be that the shorter the resistance distance, the less effort force is needed to raise the load. Students should observe that a lever has the most mechanical advantage when the fulcrum is closest to the load.

GUIDED PRACTICE

Students will practice determining ideal and actual mechanical advantage in word problems by completing five calculations involving IMA and AMA. In these problems, students should:

1. Determine what the problem is asking for and identify that variable,
2. Identify the other variables given in the problem,
3. Determine the correct formula to use to guide their calculations, and
4. Plug in all values and calculate the final answer.

This assignment will be assessed individually in class for student/teacher feedback. Teachers may save time by assigning guided practice problems for homework instead of providing time during class.

Following more instruction in this unit on work, power, and machines, students will also complete a study guide for unit review. This document and answer key is available as a separate file.

ASSESSMENT

Students will complete two assessment activities for this lesson. The assessments correspond in part to this lesson, but in whole to the unit on work, power, and machines.

ASSESSMENT 1: REVIEW GAME "AROUND THE WORLD"

Pieces for the review game "Around the World" should be prepared according to instructions in the *Teacher Preparation* section. The format is similar to the game "Around the Room." Students will work in pairs to solve 14 calculations from this lesson and the entire unit. They will need to know how to calculate force, work, power, efficiency, ideal mechanical advantage, and actual mechanical advantage. This game takes most of one 90-minute class period to complete.

Assign each pair a starting country, and on "go," they will visit that country to answer the problem. Both partners must attempt each problem on their own paper, showing all work. When an answer is reached, one partner will bring his or her paper to the teacher. After confirming accuracy, the student will be given a marker or colored pencil the color of the country he or she is "visiting," and will color that country on the world map. After returning the marker or pencil, the students will be told the next country they will "visit." Students race around the room to be the first pair to answer all 14 questions correctly. The teacher is able to assess the level of understanding as students attempt to solve each problem, answer questions, give hints, and address misconceptions on the spot. The winning pair should have a world map with the 14 countries correctly identified and colored, and the work for all 14 problems on both partners' papers.

ASSESSMENT 2: WORK, POWER, AND MACHINES TEST

Students should be allowed an entire 90-minute class period for the test on work, power, and machines. This test is written to specifically assess student learning related to North Carolina Essential Standards 3.1.3 and 3.1.4, and the learning objectives presented at the beginning of this lesson. Students will need a calculator. A reference table of formulas is provided to each student.

MODIFICATIONS

The use of technology in this lesson to project lesson notes and lab information is nice, but not necessary. The slides can be printed and given as copies to each student if needed, or even made into overhead transparencies. To save copies, you can have students generate their own data sheet and solve practice problems on their own paper, although this is not recommended for the sake of time and student engagement.

For classes with large numbers of students with special needs, teachers may want to increase groups from pairs to threes during this review game. The larger groups allow for more collaboration, which is good for weak students who might need to hear something explained more than one way. Additionally, even though students may work diligently for the entire class period, they still may not finish all problems. The winner is then the group that "visits" the most countries. This may also be an option if there is not 90 minutes available to spend on the game.

Students who receive modified tests are typically prescribed modifications in the paperwork associated with their specific situations. If you have students for whom you must modify tests, start with the original test provided here. It is simple to reduce answer choices, remove questions, and chunk information together. Beyond these simple steps, your modifications will probably vary by student.

CRITICAL VOCABULARY

Mechanical work – the measure of force applied over a distance; calculated by $\mathrm{W} = \mathrm{F}\times\mathrm{d}$, where W is work measured in Joules, F is force measured in Newtons, and d is distance measured in meters

Mechanical power – the rate of work; calculated by $\mathrm{P} = \frac{\mathrm{W}}{\mathrm{t}}$, where P is power measured in Watts, W is work measured in Joules, and t is time measured in seconds

Force – a "push" or "pull" which acts on an object and is dependent upon mass and acceleration; calculated by $\mathrm{F} = \mathrm{m}\times\mathrm{a}$, where F is force measured in Newtons, m is mass measured in grams, and a is acceleration measured in ${}^{\mathrm{m}}/_{\mathrm{s}^2}$

Weight – a measure of the force of gravity acting upon the mass of an object; calculated by $\mathrm{F_g} = \mathrm{m}\times\mathrm{g}$, where F_g is weight measured in Newtons, m is mass measured in grams, and g is acceleration due to gravity measured in ${}^{\mathrm{m}}/_{\mathrm{s}^2}$ (9.8 ${}^{\mathrm{m}}/_{\mathrm{s}^2}$ on Earth)

1st class lever – a lever with the fulcrum between the effort and load; the effort is applied down and the load moves up; the less effort required, the greater the distance the effort must be applied

Effort – the force applied to a lever to move the load

Load – the mass being moved by a lever

Fulcrum – the fixed point about which a lever moves

Ideal mechanical advantage – the expected mechanical advantage produced by a simple machine as calculated by $\mathrm{IMA} = \frac{\mathrm{d_E}}{\mathrm{d_R}}$, where d_E is the effort (input) distance and d_R is the resistance (output) distance

Effort distance – the length of a lever between the fulcrum and where the effort is applied

Resistance distance – the length of a lever between the fulcrum and where the load rests

Actual mechanical advantage – the experimental mechanical advantage determined by forces involved in the use of a simple machine; calculated by $\mathrm{AMA} = \frac{\mathrm{F_R}}{\mathrm{F_E}}$, where F_R is resistance (output) force and F_E is effort (input) force

Effort force – the force applied to a lever to move the load

Resistance force – the weight (force of gravity) of the load being lifted by a lever

WEBSITES AND RESOURCES

Basic info on 3 classes of levers
http://www.enchantedlearning.com/physics/machines/Levers.shtml

Calculating mechanical advantage of levers
http://www.edinformatics.com/math_science/simple_machines/lever.htm

Additional lever calculations
http://webs.rps205.com/curriculum/science/files/DD3CB088B41D4F01B0928002238B2EBC.pdf

The textbook used as a resource to compose this lesson is Prentice Hall's Physical Science: Concepts in Action. The item bank provided by Prentice Hall with the textbook was also used to compose some of the test items.

AUTHOR INFORMATION

Tara Blalock, a NASA Flight Fellow in the NCSU Kenan Fellows program, is the author of this lesson. She teaches at West Johnston High School in Benson, NC, which is a part of Johnston County Schools. Ms. Blalock teaches Physical Science and Chemistry to students of all grade levels (9-12). Ms. Blalock earned her bachelor's degree in Chemistry from UNC-Chapel Hill in 2008, and her Master of Arts in Teaching and comprehensive secondary science licensure from Duke University in 2009. This is her third year teaching. In 2010, Ms. Blalock was named West Johnston High School's Outstanding First Year Teacher, and was honored as a finalist for all of Johnston County Schools.

This lesson was developed as result of a summer externship with UNC's Morehead Planetarium and Science Center's External Programs educators. Ms. Blalock worked with mentors Crystal Harden and Nicholas Hoffmann to develop curriculum for their annual Science in the Summer program, geared toward elementary students. The curriculum focus for the summer of 2012 will be Simple Machines. This lesson on levers was adapted from the elementary camp curriculum to suit the needs of high school students learning about simple machines within the context of mechanical advantage, work and power.

Mentors to Ms. Blalock, Crystal Harden and Nicholas Hoffmann, both work for the Morehead Planetarium and Science Center's External Programs. Ms. Harden is the Director of External Programs. Ms. Harden has extensive experience as a science educator throughout the nation, and numerous professional experiences, honors, awards, and grants to her credit. Mr. Hoffmann is a Science Education Specialist. His experience in middle and high school classrooms in North Carolina led him to his current position at UNC where he travels the state at a science educator for the DESTINY, DREAMS, and Science in the Summer programs. Mr. Hoffmann is also a primary author for much of the curriculum for the aforementioned programs.

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