EXPLORING MECHANICAL ADVANTAGE WITH SIMPLE MACHINES

INTRODUCTION

This lesson is part of a unit on work, power, and machines. Within this lesson, students will conceptually and quantitatively explore ideal and actual mechanical advantage with three simple machines: the lever (second and third class), the inclined plane, and the pulley. Students will move throughout stations in the classroom to manipulate and collect data from each machine, and then practice calculating mechanical advantage. Students will draw conclusions from their lab experience and data.

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 take a test on these concepts.

LEARNING OUTCOMES

- During this lesson, students will explore the difference between ideal and actual mechanical advantage by manipulating and measuring components of and forces required to operate three simple machines: the lever, the inclined plane, and the pulley.
- As a result of this lesson, students will be able to identify necessary variables (effort and resistance position, effort and resistance force) on real simple machines and in word problems for the purpose of calculating ideal and actual mechanical advantage. Students will also be able to determine when to use each formula based on information provided in word problems.

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.

CLASSROOM TIME REQUIRED

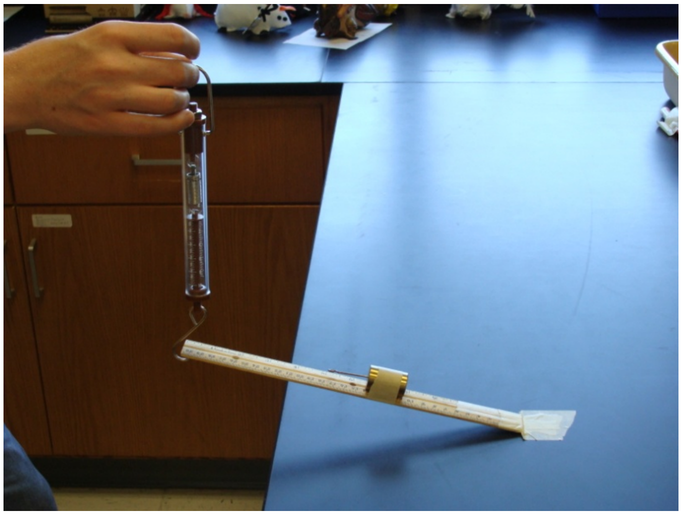
Three 90-minute block periods

TEACHER PREPARATION

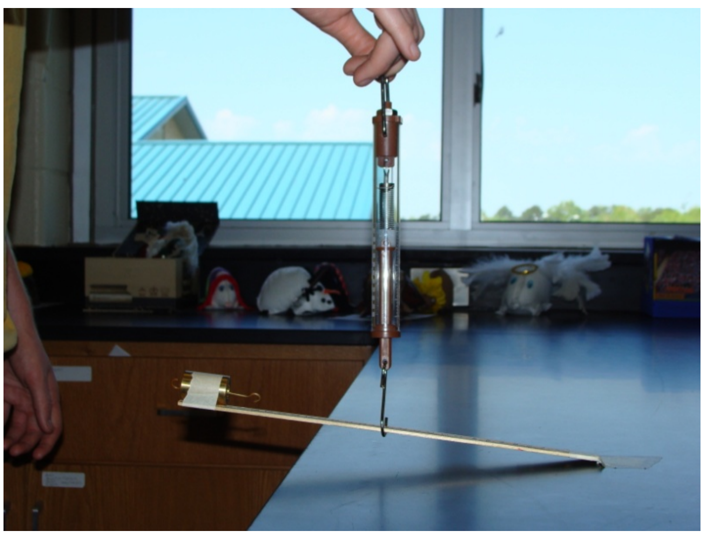
Before the activity, place the lab materials (listed below) at stations throughout the room. See photos below for a visual of each station. Have two set-ups for each station, if possible, to accommodate more students in the lab and smaller groups. Organize students into small groups; pairs work best. Make copies of student lab handouts and guided practice problems. Familiarize yourself with the pulley simulation, and verify that it will work on the computer and SMART board set-up.

Inclined Plane Station

2nd Class Lever Station



3rd Class Lever Station



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

Each student will need a lab handout and pencil or pen for recording his or her data. The handout is available as a separate file (Simple Machines Lab_Stations.doc).

For the inclined plane station (2 set-ups):

- (2) long, flat surface which can be angled as the plane such as a piece of wood
- (2) stack of books for changing the height of the plane
- (2) small cart or car to travel the plane ("Hot Wheels" cars are too small – look for a toy car for a child less than 3 years old)
- (2) spring scale to measure forces
- (2) metric ruler to measure effort and resistance positions

For the 2nd class lever station (2 set-ups):

- (2) metric ruler (wooden if possible) attached to lab bench or table with tape at the 0-cm end to act as the fulcrum
- (2) 100-g mass to act as the load
- (2) roll of masking tape for attaching the load to the lever
- (2) spring scale for measuring force

For the 3rd class lever station (2 set-ups):

- (2) metric ruler (wooden if possible) attached to lab bench or table with tape at the 0-cm end to act as the fulcrum
- (2) 100-g mass attached to ruler with masking tape as the load at the opposite end of the fulcrum
- (2) spring scale for measuring force

For the pulley station (1 set-up):

- SMART board or other interactive whiteboard
- Flash-enabled web browser navigated to http://www.compassproject.net/sims/pulley.html for the pulley simulation
- The friction for the pulley should be set to 0.15 so that IMA does not equal AMA, and the load should stay at 5 N

Students will need a pencil and calculator to complete the study guide. For assessment activities – review game and test – students will need paper, writing utensils, and calculators.

TECHNOLOGY RESOURCES

A SMART board interactive whiteboard is used in this lesson. Students will use an interactive simulation (http://www.compassproject.net/sims/pulley.html) to construct two pulley systems and collect data for calculating ideal and actual mechanical advantage.

PRE-ACTIVITIES

The lesson *Levers and Mechanical Advantage* should be taught in the class period prior to this lesson to review simple machines, to introduce the concepts of ideal and actual mechanical advantage, to introduce the experimental set-up for levers, and to familiarize students with the ause of a spring scale. For the benefit of providing students with proper background and minimizing pre-instruction for this lesson, it is recommended that *Levers and Mechanical Advantage* come before this lesson. For suggestions on teaching this lesson independent of the other, please see Modifications section.

Before beginning this lesson, students should have some prior knowledge of the concept of force, how to calculate it, and the units in which it is measured. Have a brief class discussion to review these key points.

Students will be using an Internet-based pulley simulation for this lab. Demonstrate for students how to change the type of pulley system, make the pulley work, and how to count the number of rope strands, which will determine the ideal mechanical advantage. Point out where they can read the effort force used to make the pulley work, and make sure to enforce that they should not change any other settings on the pulley other than the type.

ACTIVITIES

EXPLORATION

Pass out student lab handout and give students a brief overview of the experiment. Here is a possible script:

> *Yesterday we learned and practiced calculating ideal and actual mechanical advantage with 1st class levers. Today we're going to explore mechanical advantage in other simple machines: 2nd and 3rd class levers, inclined planes (a.k.a. ramps), and pulleys. As you move to stations throughout the room, you are going to modify each machine in two ways so that you can observe how the mechanical advantage changes. For example: at the 2nd class lever station, you will change the load position; at the 3rd class lever station, you will change the effort position; at the inclined plane station, you will change the height of the plane; and at the pulley station, you will change the type of pulley system. You must sketch the experimental set-up for both trials and record the data for each machine on your data sheet so that you can calculate mechanical advantage when you return to your seat. Before we begin, you are going to make some hypotheses.*

On their own sheets of paper, have students make predictions of how mechanical advantage will change for each station. Specifically, have them predict where the mechanical advantage will be highest and lowest based on how they will modify the machine.

- For the 2nd class lever station: Where should the load be positioned for highest mechanical advantage? For lowest mechanical advantage?
- For the 3rd class lever station: Where should the effort be positioned for the highest and lowest mechanical advantage?
- For the inclined plane station: At what height should the plane be positioned for the highest and lowest mechanical advantage?
- For the pulley station: How many components should the pulley have for the highest and lowest mechanical advantage?

Have a brief class discussion to let students share their hypotheses, but do not confirm accuracy.

MODEL SYSTEM

Pre-assembled stations will act as the model system for each simple machine type. Students already have a basic understanding of how each type of machine works and of possible ways to manipulate each machine to affect mechanical advantage based on prior instruction or in-class demonstration on the day of the activity. Students will test their hypotheses using the model systems.

EXPLORATION

In their groups and rotating to different stations, students will determine how to manipulate each simple machine based on their hypotheses. On their data sheets, they will sketch the experimental set-up for two different variations of each machine, and then record the relevant data (effort and resistance distance and force) for IMA and AMA calculations.

CONTENT WRAP-UP

After collecting data at the stations, students will return to their seats and use the data to calculate IMA and AMA. They will compare the two calculated quantities across the two trials for each machine. They should write at least one summary sentence, and one sentence confirming or refuting their hypotheses based on the results for each machine type. This should be on the same paper as their hypotheses. Students will also answer the following summary questions.

1. For the 2nd class lever station: Based on your data, where is the ideal position for the load when using a 2nd class lever
   Qualitative answers should say something along the lines of "closer to the fulcrum is best."
   Quantitative answers should state the shortest resistance distance, which should be closest to the value zero.
2. For the 3rd class lever station: Why do you think the mechanical advantage is less than 1 for this type of lever? What would be an advantage to using this type of lever?
   The mechanical advantage is always less than one because the resistance distance is always greater than the effort distance. As many students may experience, this type of lever accelerates forward quite easily past a certain point – the usefulness of a 3rd class lever is in acting like a catapult, which increases the output velocity.
3. For the inclined plane station: What causes the difference in the ideal and actual mechanical advantage for this machine?
   Friction and the angle of force applied will both cause a difference in the mechanical advantages.
4. For pulley station: What is the relationship between the effort distance and effort force as components are added to the pulley?
   As components are added, the effort (input) distance increases while the effort (input) force decreases. This is an inverse relationship.

Students should turn in their data and hypothesis/summary sheets so the teacher can check for understanding. Upon completion, engage students in a classroom discussion of their results. Encourage students to discuss their observations and conclusions, and any connections they might see to the world at large (e.g. the usefulness of simple machines).

GUIDED PRACTICE

Students will complete six practice calculations at the end of class using IMA and AMA. In these six 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 or in class for student/teacher feedback.

Students will also complete a study guide after this lesson as a summary of a unit on work, power, and machines. The study guide is to be completed on the student's time prior to the test, whether that is spare time in class or at home.

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

CLASS TIME REQUIRED

This lesson can be broken into two, 45-minute blocks if necessary. Have the students complete the lesson components through the collection of data in the lab. You may need to have students visit only a few stations on day one if they are not able to make it through all the stations. Mechanical advantage calculations from the experiment can be completed for homework and reviewed on the second day. If necessary, the experiment can be completed by visiting the remaining stations on the second day. Students will then answer summarizing and concluding questions, and complete guided practice problems using mechanical advantage.

TECHNOLOGY

Instead of the SMART board being used for the pulley activity, a desktop or laptop computer will work. A pulley kit with compound pulley parts and different weights is also a good substitute but will take longer for the students to manipulate.

PRE-ACTIVITIES

To present this lesson without first completing *Levers and Mechanical Advantage* you will need to spend some time in discussion with students reviewing simple machines, and demonstrating appropriate use of spring scales and the experimental set-ups throughout the room. You may wish to discuss mechanical advantage before the experiment, but it might be beneficial for students to discover the concept as they collect their data, to discuss their findings first, and then to learn how to and practice calculating mechanical advantage with their data.

ASSESSMENT

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.

SUPPLEMENTAL INFORMATION:

Group activities are not a time for the teacher to sit back and watch her students work. It is important to use proper classroom management technique when students are working in groups, such as in this lesson. While students are working, rotate throughout the room from group to group. Assist and explain when needed. Listen to student discussions to gauge understanding and address misconceptions. Redirect off-topic conversations. Glance at the data sheets from time to time to make sure students are accurately and precisely recording data. If it is ensured that data is collected properly to begin with, it will prevent frustration later when students are working on their calculations. Finally, give students a reasonable time limit at each station; set a timer. If students know they have a limited amount of time to complete the assignment, they will work more efficiently.

CRITICAL VOCABULARY:

Mechanical advantage – the number of times the input force is multiplied by use of a simple machine

Effort – the force applied to a simple machine to move the load

Load – the mass being moved by a simple machine

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 (input) distance – the length of the path across which the effort or input is applied to a simple machine; on levers, this is the length of the lever from the fulcrum to the point at which the effort is applied

Resistance (output) distance – the displacement of the load moved by a simple machine; on levers, this is the length of the lever from the fulcrum to the load

Actual mechanical advantage – the experimental mechanical advantage determined by forces involved in 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

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 ${}^{\mathrm{m}}/_{\mathrm{s}^2}$

Effort force – the force applied to a simple machine to move the load

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

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)

Inclined plane – a flat surface elevated at an angle; the base is flat and the other adjacent side is vertical; more or less, a 3-D right triangle where the hypotenuse is used as the machine

Pulley – a variation on the lever, a pulley includes a cable wrapped around a wheel (circular lever), which causes the wheel to rotate about its fulcrum and thus move the load; fixed pulleys change the direction of force exerted, and the more wheels added, the less force is needed; moveable pulleys simply decrease the force needed to lift a load, and the direction of the load's movement and applied force are the same

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

2nd class lever – a lever with the load between the fulcrum and the effort; the effort is applied up and the load moves up; the less effort required, the closer the load is to the fulcrum

3rd class lever – a lever with the effort between the fulcrum and the load; the effort is applied up and the load moves up; there is no mechanical advantage to using a 3rd class lever, but the distance the load moves is greater than the effort distance; this type of lever can increase power

Fulcrum – the fixed point about which a lever moves

Mechanical work – the measure of force applied over a distance; calculated by $W = F \times d$, 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 $P = \frac{W}{t}$, where P is power measured in Watts, W is work measured in Joules, and t is time measured in seconds

WEBSITES AND RESOURCES

Pulley simulation http://www.compassproject.net/sims/pulley.html

Teacher websites for more background on simple machines:

- List of links to more activities for simple machines
  http://atlantis.coe.uh.edu/archive/science/science_lessons/scienceles1/links.htm
- Lots and lots of links to information, lesson plans, and activities involving simple machines
  http://edtech.kennesaw.edu/web/simmach.html
- "Understanding Simple Machines" series of explanations and activities
  http://www.fi.edu/pieces/knox/automaton/simple.htm

Additional student websites on simple machines:

- Simple machines game (flash)
  http://www.edheads.org/activities/simple-machines/
- Examples of simple machines, matching game
  http://www.mikids.com/Smachines.htm
- Complex machines designed by Leonardo da Vinci
  http://www.mos.org/sln/Leonardo/LeosMysteriousMachinery.html

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 simple machines 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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KENAN FELLOWS PROGRAM

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North Carolina Science, Mathematics, and Technology Education Center