Forces, Levers, and Torque: Modeling the Arm as a Simple Machine

A middle and high school module in engineering

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Project Overview:

This module is the product of participation in the Summer at WSU Engineering Experience for Teachers (SWEET) Program. This five-week program incorporates collaboration with science and engineering faculty at Washington State University as well as the opportunity to work with other educators to create ways to bring an interest in engineering to the classroom. This particular module was created in collaboration with Dr. David Lin and Dr. Anita Vasavada in the specialty field of biomechanics at Washington State University.

Module Description:

This module was designed by one middle school math teacher and one high school biology teacher. The link between biology and mathematics is becoming more evident as science moves in the direction of engineering solutions to help living organisms. The purpose of the module is to introduce students to the basics of biomechanics and bioengineering through focus on the forearm and how muscles in the arm produce torque. The module is broken down into four lessons which can be used in any combination, depending on student's interests and ability level. Each lesson includes a lesson plan as well as supporting documents such as worksheets and PowerPoint presentations.

Lesson 1 introduces engineering as a career. Students will discover the endless possibilities for careers in engineering of every kind: bioengineering, petroleum engineering, civil engineering etc. In the lesson, students will research one type of engineering career in depth and report on it to a small group. We hope that through this, students will be able to focus their schooling more towards preparation for engineering in college if they are interested.

Lesson 2 focuses on Newton's laws: force and motion. Students will learn how to calculate force, how simple machines such as levers work, and what the relationship is between force and distance in levers. This lesson includes a lab activity that allows students to discover the force/distance relationship through experience.

Lesson 3 is geared towards the biology classroom. Students will learn how muscles and bone work together to create movement in the human body. A project is introduced to allow students the opportunity to investigate the several types of joints in the body. Through this, students will be ready to think more about the hinge joint of the elbow in the following lesson, and how it works to create movement in conjunction with the muscle.

Lesson 4 brings together all of the previous lessons to make mathematical predictions about the force required by muscles to keep the arm at a 90 degree angle. Solving for a single variable is a fundamental skill in algebra. Using the mathematical concepts of algebra, students will be able to solve for unknowns in their mathematical models. After this, students will test their predictions using a model of the arm system they have constructed themselves. Concepts of measurement, validity of experimentation and drawing scientific conclusions will all be addressed in this lesson.

Essential Academic Learning Requirements for the state of Washington:

Science

EALR 1: Systems

Component 1.1.6 Analyze structural, cellular, biochemical and genetic characteristics in order to determine the relationships among organisms.

Component 1.2.1 Explain inputs, outputs, transfers, transformations, and feedback matter, energy, and information in a system.

Component 1.2.8 Analyze how human organ systems regulate growth, development and life functions.

- Compare the structure and function of a human body system or subsystem to a nonliving system (i.e. human joints to hinges).

Component 1.3.1 Analyze the forces acting on objects:

- Describe how machines transform forces (e.g., a long lever allows a small downward input force to be transformed into a large upward output force.)
- Describe the strength (in Newtons) and direction of forces acting on an object.
- Measure and describe the sum of all the forces acting on an object.
- Describe how forces between objects occur, both when the objects are touching and when the objects are apart.

Component 1.3.2 Analyze the effects of balanced and unbalanced forces on the motion of an object.

- Investigate and describe that forces always come in pairs, 3rd law of motion (e.g., pull a spring scale against another spring scale, as water blasts out of a bottle rocket two forces act-a force on the water and an equal force on the rocket.)

EALR 2: Inquiry

Component 2.1.4 Analyze how physical, conceptual, and mathematical models represent and are used to investigate objects, events, systems, and processes.

- Compare how a model or different models represent the actual behavior of an object, event, system, or process.
- Evaluate how well a model describes or predicts the behavior of an object, event, system, or process.
- Create a physical, conceptual, and/or mathematical (computer simulation) model to investigate, predict, and explain the behavior of objects, events, systems, or processes (e.g., DNA replication).

EALR 3: Application

Component 3.1.2 Evaluate the scientific design process used to develop and implement solutions to problems or challenges.

- Research, propose, implement, and document a scientific design process used to solve a problem or challenge.
- Evaluate possible solutions to the problem (e.g., describe how to clean up a polluted stream).
- Evaluate the reason(s) for the effectiveness of a solution to a problem or challenge.

Component 3.2.3 Analyze the scientific, mathematical, and technological knowledge, training, and experience needed for occupational/career areas of interest.

Math

EARL 1: Concepts and Procedures of Mathematics

Component 1.1.6: Apply computational procedures with fluency on rational numbers including whole number powers and square roots of square numbers.

Component 1.2: Understand and apply concepts and procedures from measurement.

- 1.2.2: Understand and apply derived units of measurement.
- 1.2.3: Understand why different situations require different levels of precision.

Component 1.4: Understand and apply concepts and procedures from probability and statistics.

- 1.4.5: Understand and apply data techniques to interpret bivariate data.

Component 1.5: Understand and apply concepts and procedures from algebraic sense.

- 1.5.1: Apply understanding of linear and non-linear relationships to analyze patterns, sequences, and situations.
- 1.5.4: Apply understanding of equations, tables, and graphs to represent situations involving linear relationships
- 1.5.5: Understand and apply the procedures for simplifying single-variable expressions.
- 1.5.6: Understand and apply a variety of strategies to solve multi-step equations and one-step inequalities with one variable.

Pre-requisite Skills for Students

It would be helpful if students were able to do the following before starting the module. However, many things can be reviewed or taught concurrently with the lessons.

Math pre-requisites:

1. Measure a line segment perpendicular to a given line segment.
2. Compute effectively and efficiently by hand and with a calculator.
3. Judge the reasonableness of all math computations/answers.
4. Convert between units, including derived units of measure.
5. Solve single variable equations and check answers.
6. Accurately measure length in centimeters or inches.
7. Use variables and equations to represent situations.
8. Make a coordinate graph including TAILS (Title, Axis, Interval, Labels, Scale)

Science pre-requisites:

1. Understand the scientific process including formulating a hypothesis, controlling variables and recording accurate data.
2. Be familiar with SI units of measurement
3. Have a basic understanding of the laws of motion and energy (i.e. objects at rest must stay at rest, energy cannot be created nor destroyed)

Lesson 1: Exploring Career Options in Engineering

Rationale: The purpose of this lesson is to introduce engineering careers to students who might otherwise not be familiar with what an engineer does. Many areas of engineering are geared towards a specific interest/skill set that students may gravitate towards if only given the chance to learn about it.

Learning Target: By the end of this lesson, students will be able to: describe various engineering fields in the workplace today, pinpoint a specific area of engineering that interests them and describe why it does, gather and report specific information about engineering as a career.

Connection to Washington State Standards:

Science EALR 3.2.3 Analyze the scientific, mathematical, and technological knowledge, training, and experience needed for occupational/career areas of interest.

Materials:

- Options, Options, Options student worksheet-one per student
- Class set of "Engineering-Go For It!" Magazine published by the American Society for Engineering Education, www.asee.org
- Computer and internet access

Procedure:

Entry Task:

- As students enter the room, instruct them to start on the entry task immediately.
- The students will respond to the prompt below individually for discussion in class after a given time.
    - Write three things that you think about when you hear the word "engineering".
- Have students discuss in a small group or table group their ideas about engineering and why they came to those conclusions.
- Ask several students to voice common threads that all/most of the group members thought of when they were given the word "engineering".

Component #1-

- Distribute the article "Options, Options, Options"
- Distribute the worksheet that goes along with the article
- Read the instructions to the students with a reminder about writing in their own words

Component #2-

- Advise students that as they are reading and writing about the different engineering careers, they should be choosing one that interests them most.

- For Task 2, students will use the internet to answer questions about the kind of engineer they choose as most interesting.
- Students can start on this as they finish Task 1, but the expectation is that this will be finished outside of class as homework.

Assessment:

- Check student work for completion
- The following class meeting, ask students to share their chosen engineering career with the group, and why they chose it.
- As a whole class, ask students to voice any surprising facts that they found out about engineering.

Extensions:

- Assemble groups of 4 or 5 students
- Using the same magazine, have each student in the group choose a different article to read based on interest
- Allow students to read the article
- Students will discuss in their groups the articles and why they are relevant to their life and interests as a teenager.

Name___________________________________ Per.________________________

Options, Options, Options!!!!!

TASK #1:

Instructions: After reading the article “Options, Options, Options,” write a sentence or two describing each engineering career in your own words.

Aerospace Engineering

Agricultural Engineering

Architectural Engineering

Bioengineering/biomedical Engineering

Chemical Engineering

Civil Engineering

Computer/Software Engineering

Electrical Engineering

Environmental Engineering

Industrial Engineering

Materials Engineering

Mechanical Engineering

Engineering Management

Mining Engineering

Nuclear Engineering

Petroleum Engineering

Systems Engineering

TASK #2:

Instructions: Now choose one career from the list above that you are most interested in. Use the following websites (or others you can find) to help you find the answers to the questions below about that career!

www.wordiq.com, www.discoverengineering.org, www.engineergirl.org, www.engineeringk12.org

1. What type of engineering interests you most? ___________________________
2. What interests you about this type of engineer?
3. What kind of materials do they work with on a daily basis?
4. What is the starting salary for this type of engineer?
5. What kind/amount of education does a person need to become this type of engineer?

6. Find a company that hires this type of engineer. What is it and what do they do?

7. What classes will you need to continue taking or start taking NOW in order to be ready to enter this field?

8. What is a current issue/problem that engineers of this type are working on in the world today?

Lesson 2: Levers and Torque

Rationale: In order to learn and understand how forces affect body systems such as the forearm, students need to explore the idea of levers and articulate how forces affect the lever system.

Learning Target:

By the end of this lesson, students will be able to:

- Describe the relationship between distance and force in levers.
- Solve for a single variable in problems involving the three classes of levers.

Connection to Washington State Standards:

- **Science-**

1.3.1 Analyze the forces acting on objects

1.3.2 Analyze the effects of balanced and unbalanced forces on the motion of an object.

2.1.4 Analyze how physical, conceptual, and mathematical models represent and are used to investigate objects, events, systems, and processes.

- **Math-**

1.5.6: Understand and apply a variety of strategies to solve multi-step equations and one-step inequalities with one variable.

1.2.2: Understand and apply derived units of measurement.

1.5.4: Apply understanding of equations, tables, and graphs to represent situations involving linear relationships

Materials:

- "Force and Simple Machines" PowerPoint
- "Force and Levers Math" PowerPoint
- Student copies of the following-
  - See-Saw lab
  - Force and Torque practice worksheet

- Lab materials for the See-Saw lab- (for each group)
  - 1 meter stick
  - Marker (used as the fulcrum)
  - Tape
  - 24 Pennies (used for mass)
  - 50 g mass

Procedure:

Introduction:

- Students use levers every day to help make their daily tasks easier. Begin the discussion of the importance of levers by doing one of the two following things (or your own):
    - For rooms with self-shutting doors: Have one student hold the door open with their pinkie finger close to the outside edge of the door (should be very easy). Have another (stronger or larger) student attempt to hold the same door open with his or her pinkie finger near the hinge of the door. Ask the students which seemed easier, and have them begin to think about why that could be.
    - For rooms with regular hinge-open doors: Have one student use their pinkie to swing open the door positioned near the outside edge of the door. Have another student/same student attempt to open the door with their pinkie near the hinge of the door. Ask the students which seemed easier, and have them think about why that could be.
- Ask students to stand next to their desk with their backpacks in their hand. Have them observe what it feels like to hold the backpack at a 90 degree angle. Next, have the student move the backpack loop so that it is hooked over their arm halfway to the elbow. Does the backpack feel heavier or lighter? Last, ask students to move the backpack as close as they can to the elbow and hold it at a 90 degree angle. In which position did the backpack feel the lightest?

Component #1: Learning about Levers and Forces

- Use the PowerPoint entitled “Force and Simple Machines” to guide discussion and note-taking about forces and levers

Component #2: See-Saw Lab

- Gather materials for students to work in groups
- Read instructions to students and answer any questions
- Students complete lab and answer questions in small groups
- You may need to review WASL language and format for the questions and conclusion (i.e. Manipulated variable, If, then because statements, comparative language)
- Conclusions and summary of learning will be discussed with the class in Component 3

Component #3: Force and Levers Math

- Use the PowerPoint entitled “Force and Levers Math” to summarize results from the see-saw lab
- Continue through the PowerPoint for discussion of the mathematical relationship between force and distance.
- PowerPoint includes solving example problems. You will need to work these out beforehand as the solutions are not included (on the board or overhead).

Component #4: Independent practice- Torque Problems

- Distribute the worksheet “Force and Torque Practice”
- Students will complete to check for understanding of the math principles involved in solving for different variables in levers.
- Check over problems with the class and re-teach or clarify any misconceptions or problems in the students’ understanding.

Assessment:

Formative:

- Questioning students during discussion
- Questioning students during and after lab
- Review practice problems students have done individually

Summative:

- Final Written Assessment of learning targets

FORCE AND SIMPLE MACHINES

What is a force?

- A force is a push or pull.
- Forces are described not only by how strong they are, but also the direction in which they act.

•Examples- pulling your little sister in a wagon, doing a push-up

Balanced Forces

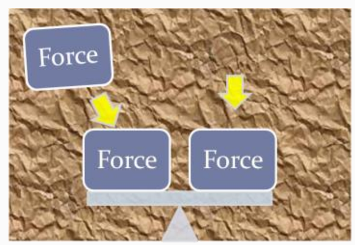
Equal forces acting on an object in opposite directions

- Balanced forces will not change an objects motion.

•FIND A PICTURE OF A TUG OF WAR FOR IN HERE

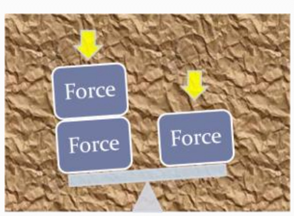
Unbalanced Forces

- Unbalanced forces can cause an object to start moving, stop moving, or change direction.



Newton's First Law of Motion

- An object will remain at rest until acted upon by an unbalanced external force



Newton's Second Law of Motion

•The force on an object is equal to the product of its acceleration and its mass.

A. Equation

Force= Mass • Acceleration

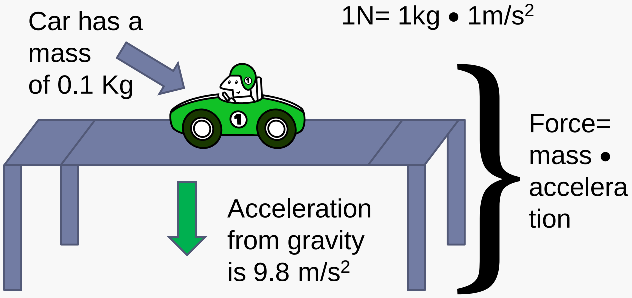
B. Units

Force= kg • m/s^2

kg • m/s^2 is called a Newton or N

1N= 1kg • $1m/s^2$

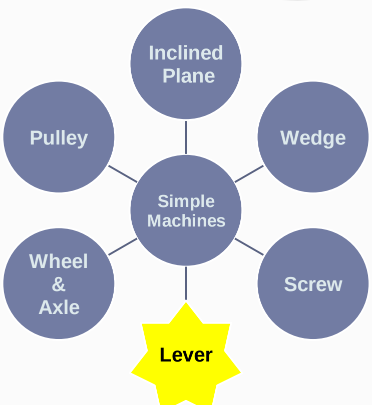
Example



0.1 Kg • 9.8 m/s^2 = 0.98 kg m/s^2 = 0.98 N downward

What is a machine?

- **A device that allows you to do work in a way that is easier or more effective.**
- **A machine can do at least one of these 3 things:**
  1. **Change the amount of force**
  2. **Change the direction of the force**
  3. **Cut down the amount of friction**

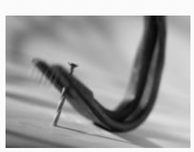


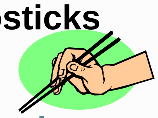
THE LEVER

- **A lever is a rigid bar that is free to pivot or rotate around a fixed point.**
- **The fixed point that the lever pivots around is called the fulcrum.**

Examples of Levers

- **Seesaw**
- **Crowbar**
- **Chopsticks**

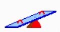


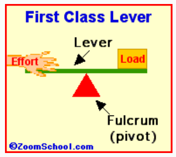


- **A lever increases the effect of your input force and changes the direction of your input force.**

3 Types of Levers

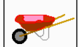
- **1st Class Lever** - the pivot (fulcrum) is between the effort and the load.

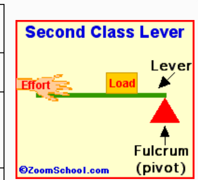
Item		Number of Class 1 Levers Used
see-saw		a single class 1 lever
hammer's claws		a single class 1 lever
scissors		Two class 1 levers
pliers		Two class 1 levers



3 Types of Levers

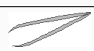
- **2nd Class Lever** - the load is between the pivot (fulcrum) and the effort.

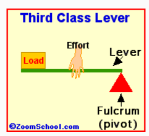
Item		Number of Class 2 Levers Used
bottle opener		a single class 2 lever
wheelbarrow		a single class 2 lever
nail clippers		Two class 2 levers
nut cracker		Two class 2 levers



3 Types of Levers

- **3rd Class Lever - the effort is between the pivot (fulcrum) and the load.**

Item		Number of Class 3 Levers Used
fishing rod		a single class 3 lever
tweezers		Two class 3 levers
tongs		Two class 3 levers



Name ____ Period ___________

Seesaw Science

Question: What is the relationship between distance from the fulcrum and mass for a balanced seesaw?

Materials:

- *Meter stick*
- *Tape*
- *Marker (used as pivot or fulcrum)*
- *Pennies (used for mass)*
- *50 gram mass*

Procedure:

1. Tape the marker to the table. This will be your pivot or fulcrum.
2. Place your meter stick on the marker so that the 55 cm mark is directly over the middle of the marker.
3. Position your meter stick so that the 100 cm mark is on your right.
4. Place a 50 gram mass on the "short side" of the meter stick. Slide the mass until the meter stick is balanced.
5. Place a stack of 8 pennies exactly over the 80 cm mark. Determine the distance in cm to the pivot. Record this distance for the right side of the seesaw.
6. Find out where you must place a stack of 5 pennies in order to balance the meter stick. Record the position for the left side of the seesaw.
7. Multiply the mass of the pennies (each penny has a mass of 0.001 Kg) by the distance to the fulcrum or pivot. Record results.
8. Repeat step 6 five times, use 7, 12, 16, and 20 pennies instead of 5.

Data:

Trial #	Side of Seesaw	# of pennies	Position of Pennies (cm)	Distance to Pivot (cm)	Force of the Pennies downward • Distance
1	**Right**	**8**	**80**	**25**	
	Left	**5**			
2	**Right**	**8**	**80**	**25**	
	Left	**7**			

3	**Right**	**8**	**80**	**25**	
	Left	**12**			
4	**Right**	**8**	**80**	**25**	
	Left	**16**			
5	**Right**	**8**	**80**	**25**	
	Left	**20**			

Seesaw Science

1 Which variable was the manipulated variable in this investigation?

2 Which variable was the responding variable in this investigation?

3 As you increase the number of pennies on the right, what happens to the distance at which you must place the stack in order to balance the meter stick?

4 What conclusion can you draw about the relationship between distances and mass needed to balance a seesaw?

5 Suppose you have a seesaw with a movable fulcrum. You want to use it with a friend who weighs half what you weigh. You and your friend want to sit at the two ends of the seesaw. *Where should the fulcrum be located?* Make a model using the materials you have to demonstrate your answer. *Draw a detailed diagram of your model below*. Include the position in cm of the fulcrum as well as the number of pennies you used.

6 If the fulcrum is 15 cm from a 100 g mass on the right side of the meter stick, can you raise a 1000g mass on the left side using a meter stick as the seesaw? If yes, what must the distance of the 1000 g mass be from the fulcrum? If not, what is the minimum mass needed to raise 1000 g using a meter stick? What would the distance from the 1000 g mass to the fulcrum have to be? Draw a diagram of the set up below.

7 Write a conclusion for this investigation.

In your conclusion, be sure to:

- Answer the investigative question.
- Include **supporting** data from the *Manipulated Variable* vs. *Responding Variable* table.
- Explain how these data **support** your conclusion.

Question: How do different *amounts of the manipulated (changed) variable*

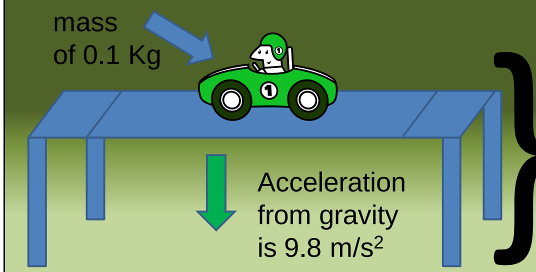
affect the *responding (dependent) variable*?

Force and Levers Math

Example

Car has a mass of 0.1 Kg

$1N = 1kg \cdot 1m/s^2$



Acceleration from gravity is 9.8 m/s^2

Force= mass · acceleration

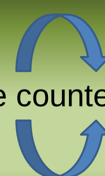
$0.1\ Kg \cdot 9.8\ m/s^2 = 0.98\ kg\ m/s^2 = 0.98\ N$ downward

Relationship between distance and force:

- What is the relationship between distance and force?
- As you increase distance from the fulcrum, you ____________________ force needed to lift the load.
- What is the relationship between distance times force on both sides of the fulcrum?

Torque

- **Torque** is
  - a force times the distance from the fulcrum
  - the ability to cause something to rotate
- If the rotation would be clockwise, the torque is positive
- If the rotation would be counterclockwise, the torque is negative



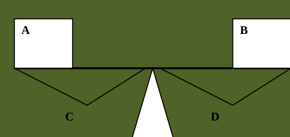
A balanced lever system

- Has torques that add up to zero
- Formula:

torque + torque = 0

or (force · distance) + (force · distance) = 0

Torque in action - First class levers

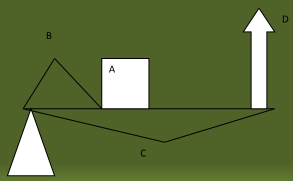


- A is the mass of the left object
- B is the mass of the right object
- C is the distance from the fulcrum to the center of object A
- D is the distance from the fulcrum to the center of object B

Problem: If the force exerted by A is 10 Newtons, the force exerted by B is 20 Newtons, the distance of C is 25 cm, **what is the distance of D**?

Step 1: What is the torque created by A? In which direction would this cause a rotation?
Step 2: What is the torque created by B? In which direction would this cause a rotation?
Step 3: The sum of all the torques on the lever is zero because it is balanced.
Step 4: Solve for the missing distance of D.

Torque in action - Second Class Levers

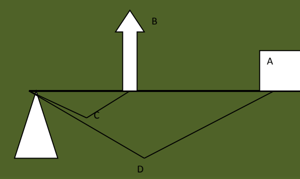


- A is the mass of the object
- B is the distance between the center of the object and the fulcrum
- C is the distance between the fulcrum and the force pulling up
- D is the force pulling up

Problem: If the force exerted by D is 12 Newtons, the force exerted by A is 18 Newtons, the distance of C is 30 cm, **what is the distance of B**?

Step 1: What is the torque created by A? In which direction would this cause a rotation?
Step 2: What is the torque created by D? In which direction would this cause a rotation?
Step 3: The sum of all the torques on the lever is zero because it is balanced.
Step 4: Solve for the missing distance of B.

Torque in action – Third Class Levers



- A is the mass of the object
- B is the force pulling up on the lever
- C is the distance from the fulcrum to the force pulling up
- D is the distance from the fulcrum to the center of the object.

Problem: If the distance of C is 10 cm, the distance of D is 45 cm, the force of A is 32 N, **what is the force of B**?

Step 1: What is the torque created by A? In which direction would this cause a rotation?
Step 2: What is the torque created by B? In which direction would this cause a rotation?
Step 3: The sum of all the torques on the lever is zero because it is balanced.
Step 4: Solve for the missing force of B.

Name____ Per_____________

Force and Torque Practice Worksheet

1. Solve for the force exerted by the objects in the picture.

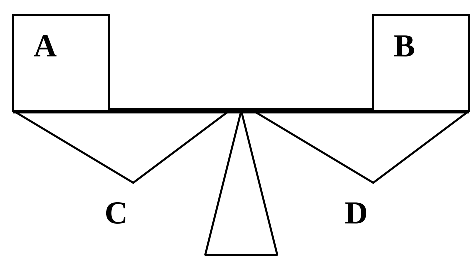
a) How much force does the snowman put on the table?

Mass of snowman is 110 grams

b) How much force would you put on the table if you sat on it? (1 pound = 453.6 grams)

c) A 20 gram spider is hanging by his web from the underneath the center of the coffee table. How much force does the spider pull on the table?

2. **First Class Lever:** Examine the teeter-totter in the picture to answer the following questions in order to **balance the teeter-totter.**



A is the mass of the left object

B is the mass of the right object

C is the distance from the fulcrum to the center of object A

D is the distance from the fulcrum to the center of object B

a) If A = 25 grams, C = 12 cm, D = 15 cm, **solve for B**.

b) If C = 80 inches, D = 30 cm, B = 45 grams, **solve for A**.

c) If A = 10 pounds, B = 19 pounds, C = 25 cm, **solve for D.**

d) If B = 1 kilograms, A = 780 grams, D = 108 cm, **solve for C.**

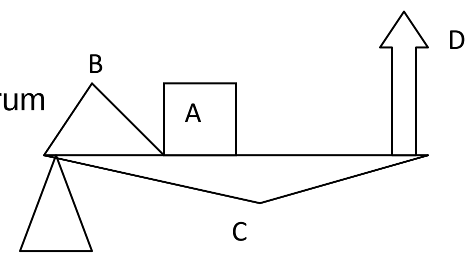
3. **Second Class Lever:** Use the picture below to answer the following questions.

A is the mass of the object

B is the distance between the center of the object and the fulcrum

C is the distance between the fulcrum and the force pulling up

D is the force pulling up



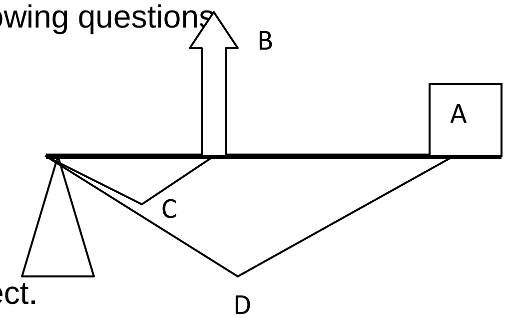
a) If A = 25 grams, B = 43 cm, C = 66 cm, **solve for D.**

b) If D = 2.4 Newtons, B = 15 inches, A = 77 grams, **solve for C.**

c) If B = 18 cm, C = 18 inches, D = 13 Newtons, **solve for A.**

d) If C = 50 cm, A = 2 pounds, D = 7.5 Newtons, **solve for B.**

4. **Third Class Lever:** Use the picture below to answer the following questions



A is the mass of the object

B is the force pulling up on the lever

C is the distance from the fulcrum to the force pulling up

D is the distance from the fulcrum to the center of the object.

a) If A = 12 Newtons, B = 20 Newtons, C = 20 cm, **solve for D.**

b) If B = 3.4 Newtons, D = 45 inches, A = 5 grams, **solve for C.**

c) If C = 13 inches, D = 50 cm, A = 4 grams, **solve for B.**

d) If D = 61 cm, C = 38 cm, B = 5.7 Newtons, **solve for A.**

Lesson 3: Muscles and Bones

Rationale: The students need to know how muscles and bones work together to allow movement in the human body. From this information, they will be able to link the forearm to the 3rd class lever in following lesson. This background information will expand the students' definitions of a joint.

Learning Target:

By the end of this lesson, students will be able to describe how muscles and bones work in conjunction to allow movement through the different types of joints.

Connection to Washington State Standards:

Science- Component 1.2.8 Analyze how human organ systems regulate growth, development and life functions.

- Compare the structure and function of a human body system or subsystem to a nonliving system (i.e. human joints to hinges).

Materials:

- "Muscles and Bones" PowerPoint
- Student copies of the joint project
- Computer access

Procedure:

Component #1:

- Use the PowerPoint entitled "Muscles and Bones" to introduce the muscular and skeletal system
- Students will take notes during the PowerPoint

Component #2:

- Introduce the "Joint Project" to students
- Review the rubric for the project and address any questions of format or content of the project
- Allow time in class and out of class for adequate research and assembly of project
- Present projects during class, either in small groups or whole-class

Assessment:

Formative:

- Review of concepts from PowerPoint prior to introduction of the joint project
- Mini-lessons with groups during the joint project work-time in order to check for understanding and clear up any misconceptions

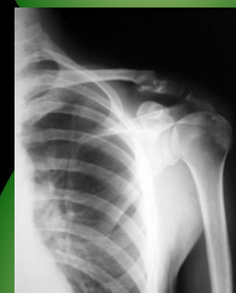
Summative:

- Assessment for this component of the module should be done outside of the module final written assessment due to the brevity of the content in relation to the module

Muscles and Bones

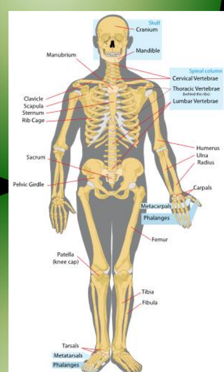
Bone Facts

- Contain living cells
- Strong and hard- yet light and flexible enough to not break easily
- 206 bones



What are the 5 functions of bones?

- **Support** the body
- Provides the basic shape
- Offers support, much like the framework of a home

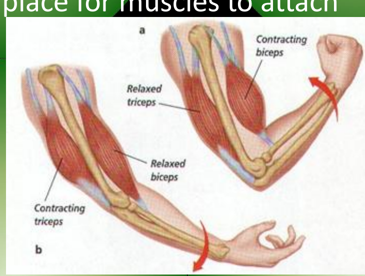


Function of bones

- **Protection** for organs in the body
  - Ex. Ribs protect the heart
  - Ex. Cranium protects the brain

Function of Bones

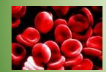
- allows **movement**
  - system of levers
  - place for muscles to attach



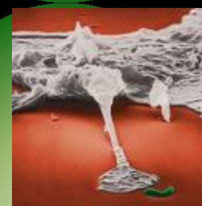
Function of Bones

- Contain reserves of minerals
  - calcium
  - phosphorus

Function of Bones



- Site of blood cell formation
  – Produces red blood cells- carry oxygen
  – Some white blood cells- fight infections
  – Platelets- help blood clot

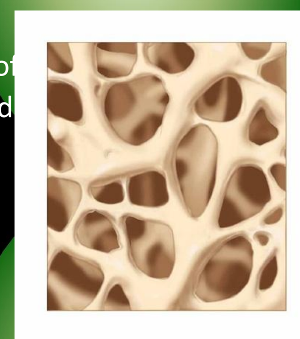


Types of Bones

- Compact bone
  – Thick, tough outer bone- made up of blood cells called osteocytes. Contain blood vessels.

Types of Bones

- Spongy bone
  – Located in the ends o long bones (femur) and in flat bones (ilium)
- The lattice-like (honeycomb) structure adds support without adding mass



Joints

- Joints- Where one bone attaches to another
- 3 categories of joints
  1. Immovable joints: Allow no movement- where two bones have fused toget Cranium
  2. Slightly Movable Joints: Small movements. Ex. Between vertebrae

Joints

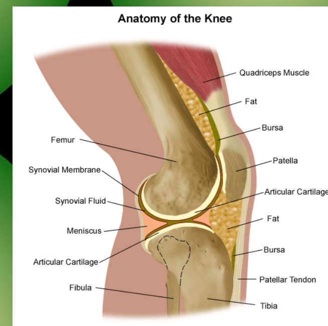
3. Freely Movable joints: Four kinds

1. Ball and socket

Shoulder- Humerus and scapula

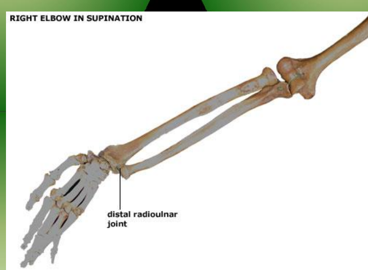
Joints

2. Hinge: Elbow and knee- Ulna/Humerus and Tibia/Femur



Joints

3. Pivot: Lower arm- Radius/Ulna



Joints

4. Saddle: Movement in all directions, Carpals in the hand

Muscles

- Types of muscle tissue include skeletal, smooth, and cardiac.

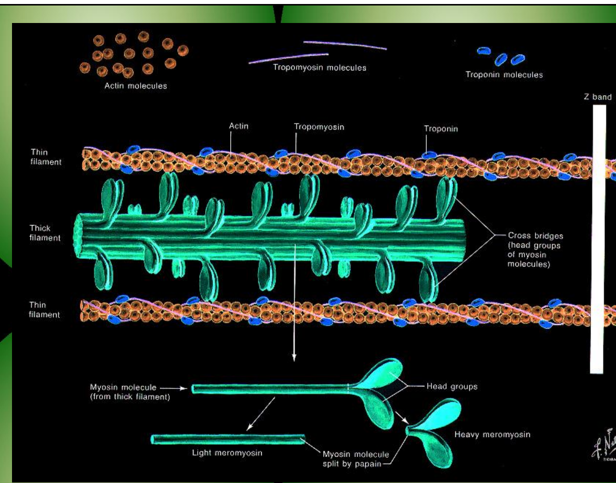
Skeletal	Smooth	Cardiac
• Attached to bones • Controlled by central nervous system (Brain and spinal cord)	• Arteries and intestines • Controlled by the autonomic nervous system	• Heart muscle cells • Controlled by the autonomic nervous system

Skeletal Muscle

- Sometimes called "striated" because of the banding pattern seen under the microscope
- Alternating pattern of actin and myosin filaments (threads)

Actin and Myosin

- Thick filaments contain a protein called myosin.
- Thin filaments are made of a protein called actin.
- These filaments are arranged along a muscle fiber in units called sarcomeres, which separated into regions called Z discs.



How a skeletal muscle contracts:

1. Brain or spinal cord sends a nerve impulse to the muscle cell through a motor neuron
2. A neuromuscular junction is the point of contact between a motor neuron and a muscle cell.
3. Vesicles at the axon terminal release the neurotransmitter acetylcholine, which causes the release of Ca^{2+} into the muscle fiber.

The calcium ions affect regulatory proteins that allow actin and myosin to interact.

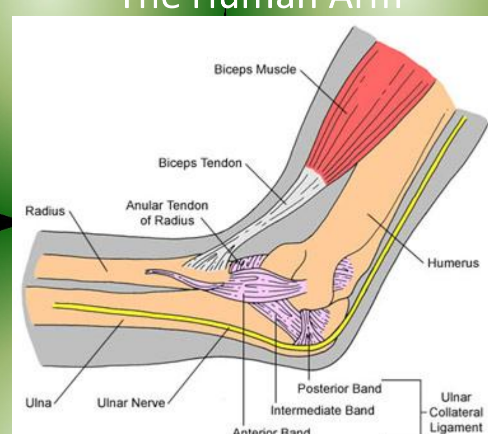
How a skeletal muscle contracts:

4. Myosin form a cross bridge with actin. Upon contraction the cross bridge changes shape, pulling on the actin, which slide toward the center of the sarcomere.
5. The distance between the Z disc decreases, the cross-bridge detaches from the actin
6. The cycle is repeated when the myosin binds to another actin.

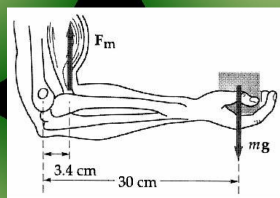
Muscles and Bones

- Skeletal muscles are joined to bones by tendons.
- Tendons are attached so they pull on a bone like a lever.
- The joint functions as a fulcrum- the fixed point around which a lever moves.

The Human Arm



The Elbow Joint as a fulcrum



Joint Project

Project:

Your job is to find household or everyday objects that display the same kind of motion as the joints in your body. The joints you need to describe are as follows:

- Ball and Socket
- Immovable
- Hinge
- Pivot
- Saddle

For each joint you need to give:

- A description of the joint
- Where it is located in the body
- A description of the basic motion and function
- An example of an everyday object that matches the joint (bringing pictures, PowerPoint, or actual objects)

Rubric:

	Not Acceptable	Mediocre	Acceptable
Thoroughness	3 or less joint types are included	All but one joint type is included	All five joint types are included
Creativity	No color or creativity	Creative but no use of color	Colorful and creative
Location	No description or false description of the location of the joint in the body	A description of the general area of the joint (i.e. "In the arm")	A full description of the location of the joint, including surrounding organs, muscles or bones
Motion and function	No description of the basic motion and function	Basic description of the motion and function	It is clear that you understand the motion and function of the joint above and beyond what we learned together in class

Object example	Crummy example (false) or no example object for each joint type	All but one object is creative and correctly shows the relationship between everyday objects and our body	All examples show how everyday objects can be likened to the joints in our body correctly and creatively

Grading:

Work that is not acceptable will receive a grade of 0-10 points

Mediocre work will receive a grade of 11-20 points

Acceptable work will receive a grade of 21-30 points

EXTRA CREDIT is possible up to 5 points for exceptional projects

Lesson 4: The Arm as a Lever

Rationale: Students have learned that levers are important tools used every day to help make our lives easier. Levers are also used in the human body to decrease the magnitude of the force needed to carry a load or resistance. In this lesson, students will make mathematical predictions about the force required by muscles to keep the arm at a 90 degree angle. Solving for a single variable is a fundamental skill in algebra. Using the mathematical concepts of algebra, students will be able to solve for unknowns in their mathematical models. After this, students will test their predictions using a model of the arm system they have constructed themselves. Concepts of measurement, validity of experimentation and drawing scientific conclusions will all be addressed in this lesson.

Learning Target:

By the end of this lesson, students will be able to:

- Set up linear torque equations in order to solve for either distance or force
- Solve equations with a single variable
- Take force and distance measurements in an experimental model of the arm
- Make observations and draw conclusions about the relationship between the attachment point of a muscle and the amount of force required

Connection to Washington State Standards:

- **Science-**
  1.2.1 Explain inputs, outputs, transfers, transformations, and feedback matter, energy, and information in a system
  1.3.1 Analyze the forces acting on objects
  1.3.2 Analyze the effects of balanced and unbalanced forces on the motion of an object.
  2.1.4 Analyze how physical, conceptual, and mathematical models represent and are used to investigate objects, events, systems, and processes.
  3.1.2 Evaluate the scientific design process used to develop and implement solutions to problems or challenges.

- **Math-**
  1.2.2: Understand and apply derived units of measurement.
  1.2.3: Understand why different situations require different levels of precision.
  1.1.6: Apply computational procedures with fluency on rational numbers including whole number powers and square roots of square numbers.
  1.4.5: Understand and apply data techniques to interpret bivariate data.
  1.5.4: Apply understanding of equations, tables, and graphs to represent situations involving linear relationships
  1.5.6: Understand and apply a variety of strategies to solve multi-step equations and one-step inequalities with one variable.
  1.5.5: Understand and apply the procedures for simplifying single-variable expressions.

Materials:

- Lesson 4 “Elicitation Question Worksheet”
- “Arm practice problems” document
- Student copies of the “Wooden Arm Lab”
- Optional: model of the human arm
- Master Materials List for lab:
    - Two 8-inch pieces of 3/8 inch doweling
    - Fishing line (about a foot and a half long)
    - One 7/8 inch medium screw eye
    - One ½ inch screw eye
    - Four 7/16 inch small screw eyes
    - One 1 in. machine screw size 4-40
    - Two size 4-40 hex nuts
    - One size 4-40 lock washer
    - One 10cm X 2 cm X 6 cm (approximate) wood or plastic block
    - One size 12 fishing barrel swivel
    - One set of gram masses
    - One 2.5 N spring scale
    - One ruler, scissors and calculator
    - One pair of needle nose pliers
    - Drill with drill bits (size 32, and size 56)
    - Wood glue or masking tape

Procedure:

Introduction:

- Review question: What is a lever?
- Ask students to list (in groups or individually) as many parts of the body that could be considered a lever. If they can, have them write down if each is a first, second or third class lever.

Component #1: Elicitation Journaling

- In small groups, students will complete the journal questions to elicit thought and ideas about how the forearm is related to a lever.
- Lead a whole-class discussion on some or all of the questions in the journaling prompt.

Component #2: Practice problems with the arm

- Use the guide entitled "Arm Practice Problems" to model solving for a single variable (on whiteboard, overhead etc.) how you see fit. The purpose of this is to provide a venue for students to practice solving the kind of math that will be needed in the upcoming lab.
- Allow students to work through problems individually or in small groups to check for understanding

Component #3: Wooden Arm Lab

- Read through the instructions for assembly of the model arms
- Some pre-drilling and cutting work will need to be done outside of lab time by the teacher or capable students
- Gather all materials for small groups of 4-5 students per model kit
- Students will construct the wooden arm in one of three ways (depending on the characteristics of the students):
    - Students are given no instructions but all materials and a description of the intended function of the model
    - Students are given limited instructions, including the schematic of the model
    - Students are given detailed instructions for assembly and a schematic of the model
- Have students read through the lab before working. Notice that all mathematical predictions need to be formulated BEFORE data is taken.
- Data tables are provided, but graph paper may need to be supplied for the graphing portion of the discussion questions in the lab
- WASL conclusion tutorial and master template are located in the appendix of this module

Component #4: Discussion of module lab conclusions

- Students have concluded that the further the muscle attachment is from the fulcrum (elbow) the smaller the magnitude of the force needed to hold a mass at a 90 degree angle. This leads to a discussion about why our muscle is not attached further down the forearm.
- Students may be able to offer ideas about why the muscle in the human arm is not attached at the middle to end of the forearm.
- Some biomechanical reasons for the location of the muscle attachment include:
  - The skin has to cover the entire system, therefore the human arm would have a web connecting the forearm to the upper arm.
  - As the attachment point moves outward from the fulcrum the length of contraction of the bicep increases proportionately. The increase in length causes an increase in the amount of time it takes for the muscle to contract. Therefore muscles with longer attachment points tend to contract slower, which is a trade-off in biological function. Slower contraction times affect the power that can be generated by the muscle in each contraction.

Assessment:

Formative:

- Discussion of the elicitation questions to check for students' ability to connect the lever to the model arm.
- Feedback from students working with the teacher on the arm practice problems
- Wooden arm lab discussion questions

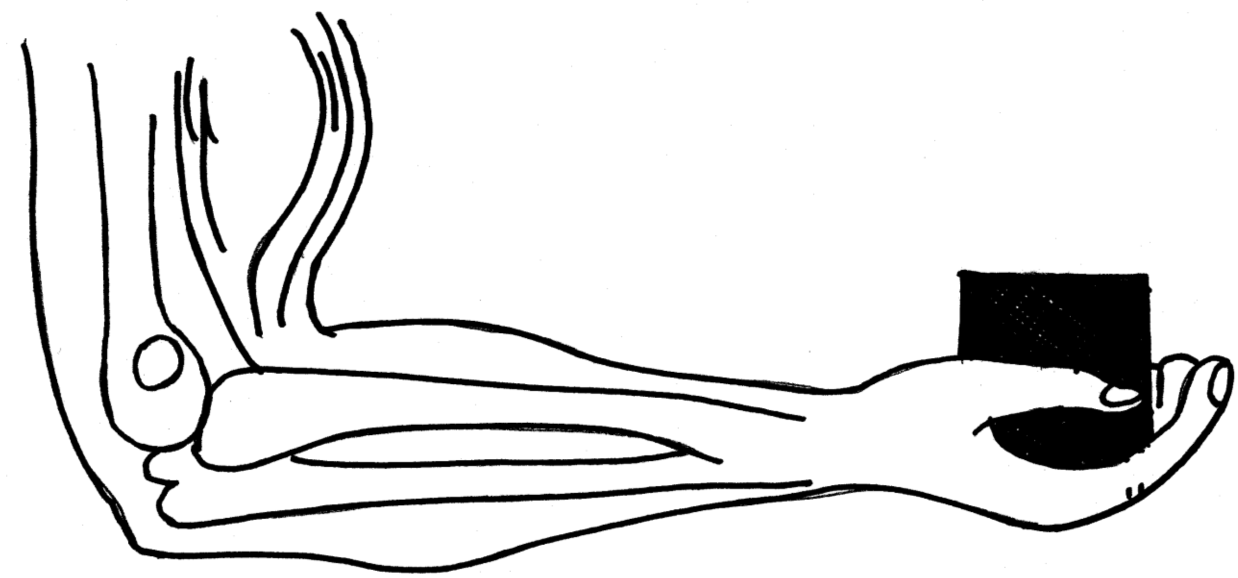
Summative:

- Wooden arm lab conclusion
- Final written assessment

Name__________________________________ Per.______________________

Pre-Lab Journaling and Discussion Questions

Directions: Answer each question in your small group, looking at the diagram to guide your thinking.



1. Looking at the picture, what parts of the diagram look like a lever? Do you see a fulcrum? Where?

2. Observe the bones of the forearm. How many are there, and how are they arranged?

3. Look at the muscle. Where does the muscle attach onto the bones of the arm? Do you know what that muscle is called?

4. What kind of joint is the elbow joint in the human body?

5. Looking at the forearm as a lever, would this be a first, second, or third class lever? Why? (Hint: where is the fulcrum, the input force and the output force?)
6. If you were holding a heavy block in your hand, what direction would the force of the block be on your hand?

7. What other force could cause this lever to be balanced? What force in the opposite direction causes the block to hover in your hand and stay level?

8. Look at where the muscle attaches to the bone. How far away from the fulcrum is this?

9. Does the muscle exert a push or a pull on the bones of the forearm?

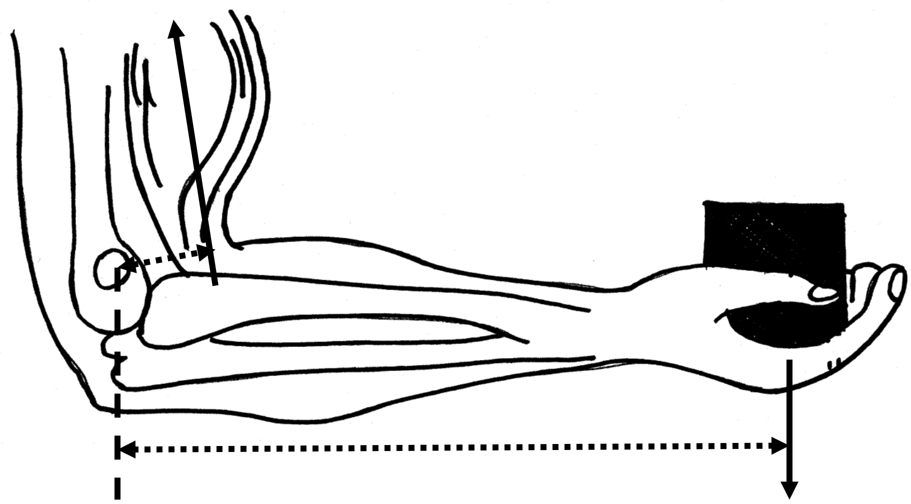
10. Do you think if you changed the site of muscle attachment it would change the amount of force you need to keep the block at a 90º angle? Explain your reasoning.

11. If you increased the mass of the block in the hand (and kept the forearm at 90º to the upper arm) what effect would it have on the rest of the system? What forces would increase, decrease, or stay the same?

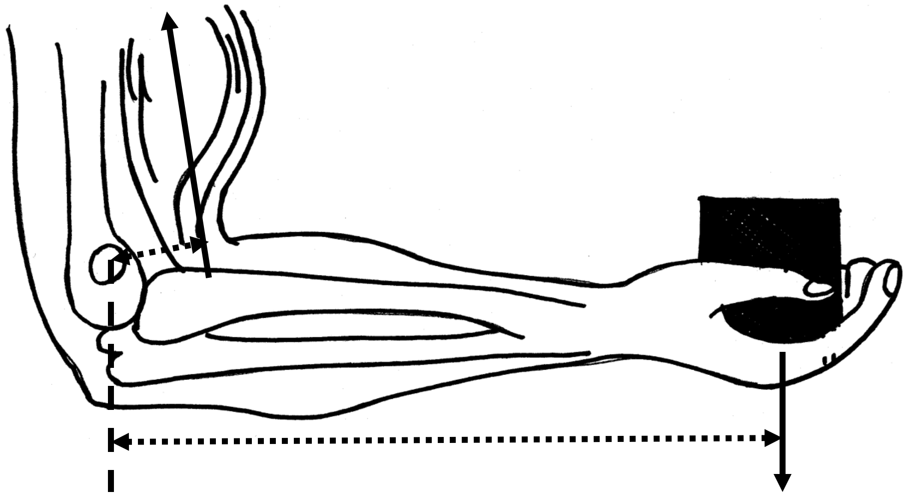
Arm Practice Problems

Instructions to the teacher: Use these problems as you wish-they were intended to be used as modeling in front of the class in order for students to learn how to relate the arm to a lever.

#1



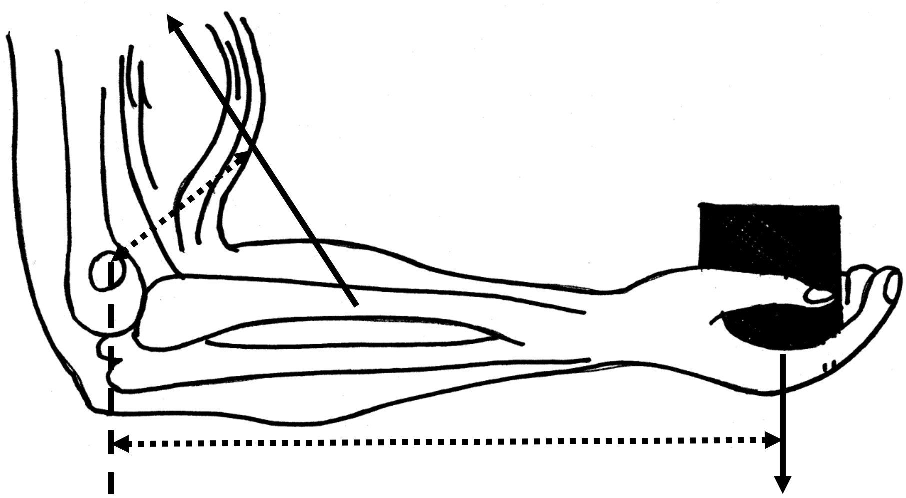
- The mass of the block is 10 g
- The distance from the fulcrum to the block is 30 cm
- The Perpendicular distance from the fulcrum to the line of action (of the muscle) is 5 cm
- What is the force of the muscle pulling the arm in the upward direction to keep the arm at 90°?



Problem #2

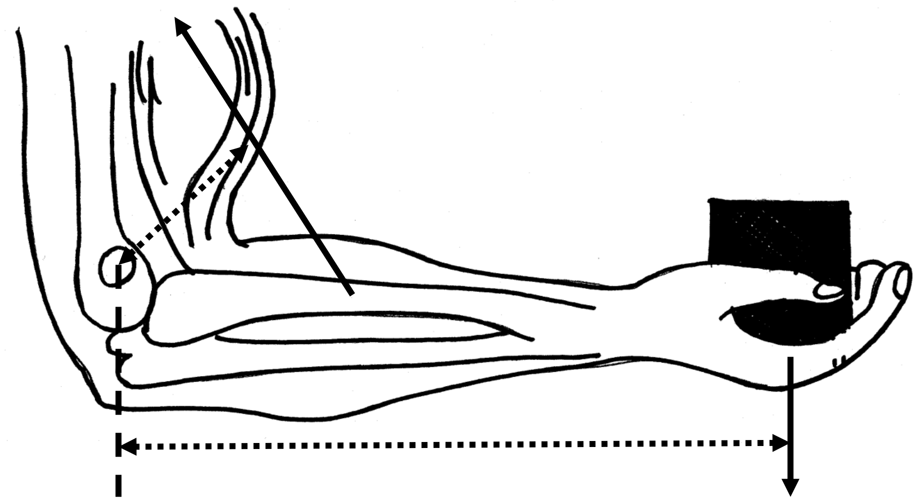
- The mass of the object is 50 g
- The perpendicular distance is 8 cm
- The force of the muscle is 3 N
- What is the distance from the fulcrum to the mass?

Problem #3



- The force of the muscle is 5 N
- The perpendicular distance is 6 cm
- The distance from the fulcrum to the mass is 18 cm
- What is the mass of the block?

Problem #4



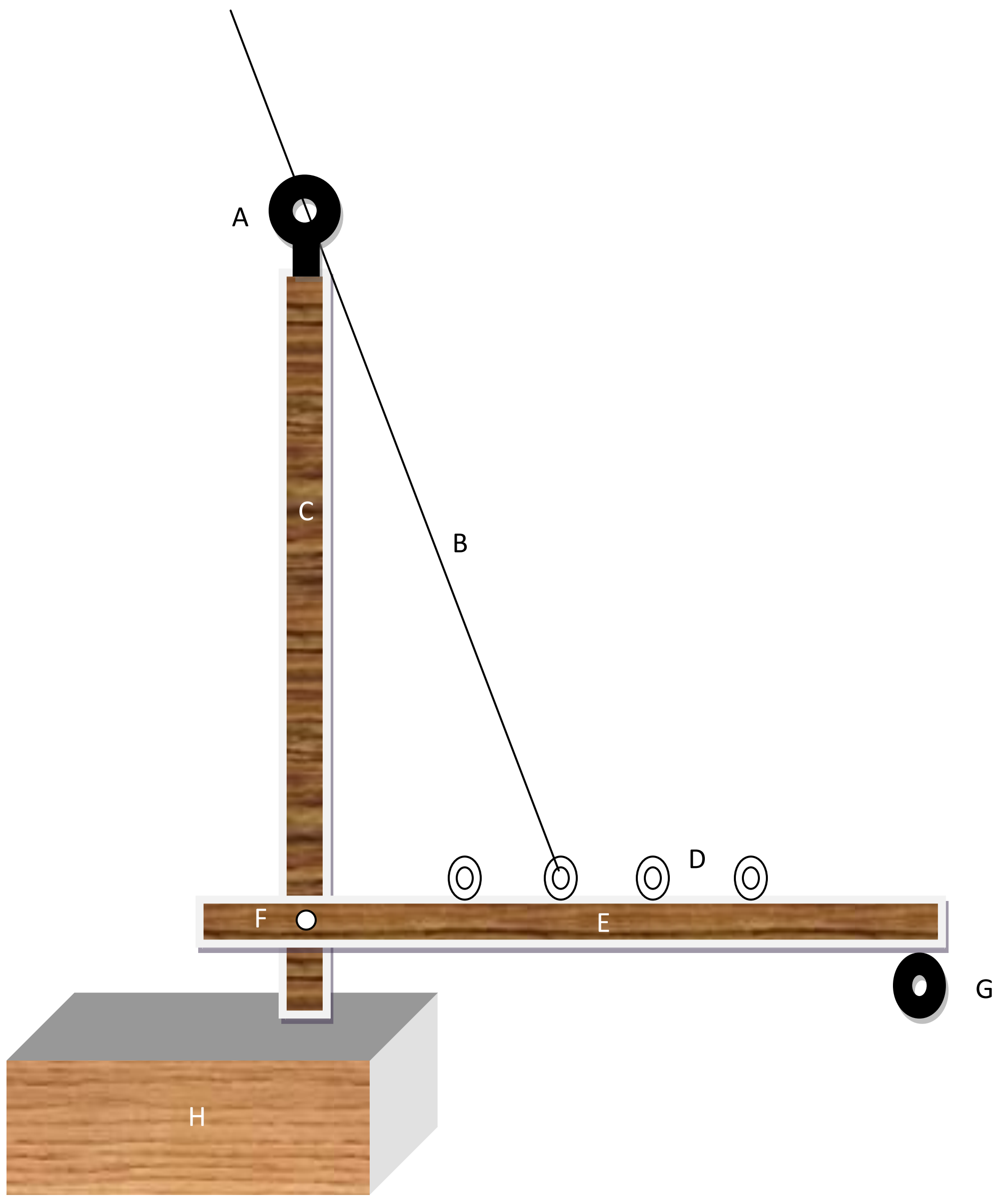
- The mass of the block is 0.067 kg
- The perpendicular distance is 7 cm
- The distance from the fulcrum to the mass is 35 cm
- What is the force of the muscle?

ANSWER KEY:

1. 0.59 N
2. 48.98 cm
3. 0.17 Kg
4. 32.83 N

Schematic of Arm Model

A. Size 7/8 in. medium screw eye
B. Fishing line
C. 3/8 in. wood doweling, 8 inches long
D. Size 7/16 in. small screw eyes (4)
E. 3/8 in. wood doweling, 8 inches long
F. 1 inch size 4-40 machine screw, with 2 size 4-40 hex nuts, 1 size 4-40 lock washer
G. Size ½ in. screw eye
H. Wood block approximate dimensions 10cm X 2 cm X 6 cm



Instructions for Assembly of Arm Models

Master Materials List:

- Two 8-inch pieces of 3/8 inch doweling
- Fishing line (about a foot and a half long)
- One 7/8 inch medium screw eye
- One ½ inch screw eye
- Four 7/16 inch small screw eyes
- One 1 in. machine screw size 4-40
- Two size 4-40 hex nuts
- One size 4-40 lock washer
- One 10cm X 2 cm X 6 cm (approximate) wood or plastic block
- One size 12 fishing barrel swivel
- One set of gram masses
- One 2.5 N spring scale
- One ruler, scissors and calculator
- One pair of needle nose pliers
- Drill with drill bits (size 32, and size 56)
- Wood glue or masking tape

Pre-Assembly Instructions (for the facilitator)

1. Cut doweling into 8 in. pieces
2. Measure 3 cm in from the ends of each dowel and mark center
3. Drill hole through each with a size 32 drill bit
4. Rotate one dowel 90º so that the hole going through the dowel is horizontal
5. Mark out 4 holes, starting 6-7 cm from the end that has already been drilled. Space these about 2.5 cm apart
6. Pre-drill these 4 holes with a size 56 drill bit (for ease of screwing in eyehooks by students)
7. On the same dowel 1-2 centimeters from the other end, turn completely over and pre-drill another hole with the same drill bit
8. On the other dowel, pre-drill a hole with a size 56 drill bit directly into the cross-section of the dowel
9. Drill a hole with large enough to fit a 3/8 dowel into one centimeter from the edge of the 6 X10 face of the wooden block

Student Materials List:

- Two 8-inch pieces of 3/8 inch doweling
- Fishing line (about a foot and a half long)
- One 7/8 inch medium screw eye
- One ½ inch screw eye
- Four 7/16 inch small screw eyes
- One 1 in. machine screw size 4-40
- Two size 4-40 hex nuts
- One size 4-40 lock washer
- One 10cm X 2 cm X 6 cm (approximate) wood or plastic block
- One size 12 fishing barrel swivel
- One set of gram masses
- One 2.5 N spring scale
- One ruler, scissors and calculator
- One pair of needle nose pliers
- Wood glue or masking tape

Instructions for Students

1. Gather all materials.
2. In the piece of doweling with four holes drilled along the center, screw in the four size 7/16 in. (smallest) eyehooks with the needle nose pliers.
3. Locate the hole on the underside of the dowel. Screw in the size ½ in. (medium) eyehook.
4. On the other dowel, locate the hole on the cross-section of one side. Screw in the size 7/8 in. (largest) eyehook.
5. Insert the end of this dowel into the block of wood, using wood glue or tape to secure the hold (if necessary) MAKE SURE that the hole in the bottom is parallel to the 2 X 6 face of the wood block.
6. When the dowel is secure, turn the eyehook so that it is parallel to the hole through the dowel.
7. Connect both dowels with the 1in screw so that the 4 small eyehooks in a row are facing the ceiling.
8. Put on one hex nut, followed by the lock washer, and finished with the other hex nut. Screw in just enough so that the pivot moves freely with little friction.
9. Tie fishing line into the small loop at the end of the barrel swivel.
10. Tie a loop at the other end of the fishing line big enough to put a finger through.

Name____ Per_________________

The Wooden Arm Lab

Problem: What is the relationship between the muscle's site of attachment and the amount of force the arm requires to hold a given object at a 90° angle?

You have built a model of the human forearm. Unlike a human, your model has the ability to change the site of muscle attachment. What will this do to the force required to hold a mass? Look at the model and see the sites of attachment. Do you notice that some are close to the fulcrum and some are far from it?

1. Read through the procedure. What is your manipulated (independent) variable? _______________________________
2. What is the responding (dependent) variable? _________________________
3. Write a hypothesis for this problem (remember If….Then…BECAUSE!)

Procedure:

1. Gather the arm model, calculator, ruler, pencil, spring scale and mass set
2. Label the attachment points on the dowel 1-4 starting with the point closest to the fulcrum
3. Make a mathematical prediction of the force needed to keep the arm at 90° while holding a mass of 50 g at attachment at the first attachment point and record in the data table.
4. Hook the barrel swivel to attachment point 1, pulling the fishing line up through the eyehook at the top of the arm. Feel that the arm moves fluidly up and down.
5. Hold down the wooden block for stability
6. Hook the spring scale into the loop at the top of the fishing line
7. Hanging the forearm off of the lab table, hook the 50g mass to the eyehook on the underside of the dowel.
8. Pull the spring scale upwards, exerting as little friction as possible on the fishing line and eyehook, until the dowels form a 90° angle at the fulcrum.
9. Read the force with the spring scale and record in Newtons on the data table.
10. Repeat steps 1-7 for each attachment point three times to increase validity and record. (Remember to make your mathematical prediction BEFORE you take any data!!)
11. Compare data with other groups to increase validity of results.

Prediction (N) Trial Number

			1	2	3
Attachment Point	**#1**				
	#2				
	#3				
	#4				

Discussion:

1. Prepare a coordinate graph with the data.
2. Looking at the graph, what do you notice about the relationship between the variables?

3. What variables did you control in this investigation?

4. How did you ensure validity in your results?

Conclusion:

Write a conclusion for this investigation.

In your conclusion, be sure to:

- Answer the investigative question.
- Include **supporting** data from the *Manipulated Variable* vs. *Responding Variable* table.
- Explain how these data **support** your conclusion.

Question: How does changing the *of the manipulated (changed) variable*
affect the *responding (dependent) variable*?

EXTENSION ACTIVITY- Now that you have investigated the relationship between muscle attachment site and force, here is another investigative problem to examine.

Problem: What is the relationship between the mass held by the arm and the force required by the muscle to keep the arm at 90º?

1. Make a mathematical prediction of the force needed to keep the arm at 90º while holding a 10 g mass at your group's assigned attachment point and record in the data table. Our group's attachment point is ________________
2. Hook the barrel swivel to your assigned attachment point, pulling the fishing line up through the eyehook at the top of the arm. Feel that the arm moves fluidly up and down.
3. Hold down the wooden block for stability
4. Hook the spring scale into the loop at the top of the fishing line
5. Hanging the forearm off of the lab table, hook the 10 g mass to the eyehook on the underside of the dowel.
6. Pull the spring scale upwards, exerting as little friction as possible on the fishing line and eyehook, until the dowels form a 90º angle at the fulcrum.
7. Read the force with the spring scale and record in Newtons on the data table.
8. Repeat steps 1-7 for each mass (20 g, 30 g, 40 g) three times to increase validity and record. (Remember to make your mathematical prediction BEFORE you take any data!!)
9. Compare data with other groups to increase validity of results.

		Prediction (N)	Trial Number		
			1	**2**	**3**
Mass (g)	**10 g**				
	20 g				
	30 g				
	40 g				

Discussion:

1. Prepare a coordinate graph with the data.
2. Looking at the graph, what do you notice about the relationship between the variables?

3. What variables did you control in this investigation?

4. How did you ensure validity in your results?

Conclusion:

Write a conclusion for this investigation.

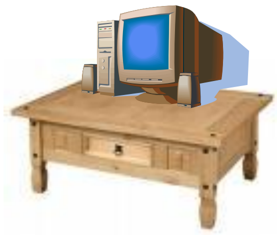
In your conclusion, be sure to:

- Answer the investigative question.
- Include **supporting** data from the *Manipulated Variable* vs. *Responding Variable* table.
- Explain how these data **support** your conclusion.

Question: How does changing the *of the manipulated (changed) variable*
affect the *responding (dependent) variable*?

Final Assessment:

1. Find the force the computer pushes on the table if the computer has a mass of 1200 grams.



2. Your kid brother decides to stand on the table. Find the force he exerts on the table if he weighs 33 pounds (1 pound = 453.6 grams).

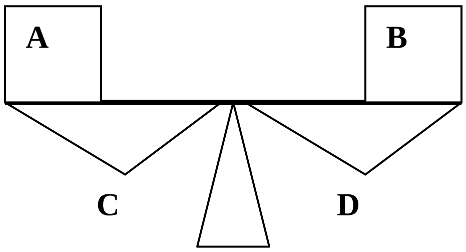
3. Examine the teeter-totter in the picture to answer the following questions in order to **balance the teeter-totter.**

A is the mass of the left object

B is the mass of the right object

C is the distance from the fulcrum to the center of object A

D is the distance from the fulcrum to the center of object B



a) If A = 2.2 kg, B = 880 grams, C = 120 cm, **what is the distance of D**?

b) If C = 4.5 inches, B = 7.4 kg, D = 20 cm, **what is the mass of A**?

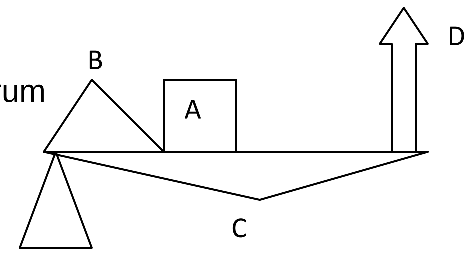
4. Use the picture to the right to answer the following questions about force and distance in order to keep the lever horizontal.

A is the mass of the object

B is the distance between the center of the object and the fulcrum

C is the distance between the fulcrum and the force pulling up

D is the force pulling up



a) If A = 2 Newtons, B = 29 cm, D = 1.5 Newtons, **what is the distance of C**?

b) If D = 985 grams, C = 14 inches, B = 14 cm, **what is the force exerted by A**?

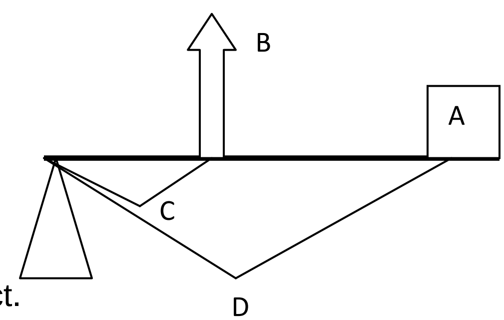
5. Use the picture to the right to answer the following questions about force and distance in order to keep the lever horizontal.

A is the mass of the object

B is the force pulling up on the lever

C is the distance from the fulcrum to the force pulling up

D is the distance from the fulcrum to the center of the object.



a) If A = 10 pounds, B = 250 N, C = 90 cm, **what is the distance of D**?

b) If D = 60 inches, C = 25 inches, A = 550 grams, **what is the force exerted by B**?

6. Name three types of engineering. What is the focus or purpose for each kind of engineer?

7. Describe the relationship between distance and force in a lever system.

Appendix A: Science and Engineering (www.wordiq.com)

Engineering: Originally, the art of managing engines; in its modern and extended sense, the art and science by which the properties of matter are made useful to man, whether in structures, machines, chemical substances, or living organisms; the occupation and work of an engineer. In the modern sense, the application of mathematics or systematic knowledge beyond the routine skills of practice, for the design of any complex system, which performs useful functions, may be considered as engineering, including such abstract tasks as designing software.

Engineering has been called the "invisible profession" or the "stealth profession" because most people have no clue what engineers do. This is unfortunate, because everything in society is linked to engineering.

Science: A method of learning about the physical universe by applying the principles of the scientific method, which includes making empirical observations, proposing hypotheses to explain those observations, and testing those hypotheses in valid and reliable ways. Science also refers to the organized body of knowledge that results from scientific study

Engineering and Science

Similarities and Differences

It is the conventional wisdom of laymen that if you want a really great engineer you get a scientist. For example, the presidential commission investigating the Challenger disaster included the great theoretical physicist Dr. Richard Feynman, but no engineers. As a result Dr. Feynman, who never heard of O-rings before, was successfully misled in a cover-up and the public never found out that the failure was due to engineering negligence, a dimension error in the O-ring grooves and not to low temperature. One should no more call upon a scientist to explain why a machine does not work properly than to call upon an engineer to explain a nuclear phenomenon.

Engineering is neither better nor worse than science, but it is different. The basic objective of science is to discover the composition and behavior of the physical world, the "laws of nature" (better described as the "facts of nature;" they are not the result of legislation.) The basic objective of engineering is to design useful things. Since useful things must "obey" the laws of nature, engineers study science. Since observing nature requires certain useful things - scientific instruments - experimental scientists do a good deal of engineering. In practice, the work of real-world scientists and real-world engineers overlap to some degree. Experimental scientists "do" engineering in designing the hardware of their experiments and some engineers "do" scientific experiments in developing new useful things. In some areas, such as semi-conductor research, scientists and engineers work together in an undistinguishable way; the boundaries between the two activities are blurred and unimportant.

"Theoretical" scientists and "theoretical" engineers do not perform experiments but think and calculate based on the data produced by experimental scientists and engineers. Some engineers and scientists do both. The training of scientists and engineers are similar but different. Both learn basic science and the associated mathematics. (A "useful thing" must conform to the laws of nature or the thing will not be useful.) Scientists learn more advanced science so they can further advance science. Most study until they achieve a Ph.D. so they are qualified to make further discoveries. Engineers study subjects, which are specifically useful in designing useful things but are, for the most part, not useful to scientists. Examples are the strength of beams and the performance of motors. Most engineers are qualified for useful work without reaching the Ph.D. in college.

Compared to other professions

Engineering is concerned with the implementation of a solution to a practical problem. A scientist may ask "why?" and proceed to research the answer to the question. By contrast, engineers want to know *how* to solve a problem and how to implement that solution. In other words, scientists investigate phenomena, whereas engineers create solutions to problems or improve upon existing solutions.

The terms "engineer" and "technologist" are not interchangeable; both describe different types of work and different professions. To illustrate: Once engineers have found a solution for the problem at hand, their work stops, and technologist begin the work of improving the solution. This process is dependent on various factors that vary with time. A solution that could be a practical application of a scientific fact does not satisfy a technologist. A technologist endeavors to bring it within the economic constraints so that the common person not only understands and marvels at science but also is able to enjoy it and loses fear of it by constant interaction.

As an illustrative example, on November 21, 1877, Thomas A Edison developed the phonograph, a remarkable feat of engineering. Then, he directed his assistant (the technologist) to improve the device further by removing harmonics from the sound output.

The task of engineering

The engineer must identify and understand the relevant constraints in order to produce a successful design. Constraints include available resources, physical or technical limitations, flexibility for future modifications and additions, and other factors such as requirements for cost, manufacturability, serviceability, and marketing and aesthetic, social, or ethic considerations. By understanding the constraints, engineers deduce specifications for the limits within which an object or system may be produced and operated. Engineering is therefore influenced by many considerations.

Engineers help to design and manufacture just about everything, from the tallest skyscrapers to the smallest computer chips, from cars to space shuttles, from miracle fabrics to artificial heart valves. Even though their efforts are all around us, the work of engineers can seem like a mystery to those outside the profession.

“You grow up knowing what teachers and doctors and lawyers do. But unless your parents happen to be engineers, you probably don't have a clue what their work involves," says a woman who grew up to be a successful environmental engineer.

Types of Engineering: The "Big Four"

In the most general terms, engineers are problem-solvers. They apply the concepts of mathematics and science to solving real world challenges.

The engineering profession includes many different disciplines. In fact, engineering may offer more career options than any other profession. Engineers are a diverse group, contributing to projects that improve the quality of life on every continent. A background in engineering can also lead to a career in law, education, medicine, or public policy.

Here's a look at four of the largest categories within the profession: chemical engineering, civil engineering, electrical and computer engineering, and mechanical engineering.

- ***Chemical Engineering***
  Take a walk through your grocery store, pharmacy, or paint store, and you'll see hundreds of examples of what chemical engineers create. Chemical engineers combine the science of chemistry with the principles of engineering to produce better plastics, fuels, fibers, semiconductors, medicines, building materials, cosmetics, and much more. Their know-how has helped to develop reduced-calorie sweeteners, lead-free paint, fibers that can withstand the heat of forest fires, and thousands of other products.

  Chemical engineers work in a variety of settings, from research laboratories to food-processing plants to pharmaceutical companies, and universities. They tackle challenges relating to agriculture, environmental pollution, and energy production. Sometimes they even work at the molecular level to create brand-new synthetic materials.

- ***Civil Engineering***
  Civil engineers help to create the building blocks of modern society. They work with many different structures, from dams and highways to bridges and buildings, the products of civil engineering are all around us. Civil engineers belong to one of the oldest and largest branches of engineering. They use cutting-edge technologies and advanced materials to solve challenges in new ways.

  A background in civil engineering opens the door to a variety of career options. According to the American Society of Civil Engineers, areas of focus include construction engineering, environmental engineering, structural engineering, as well as transportation, urban planning, and water resources.

- ***Electrical and Computer Engineering***
  Electrical engineering has been one of the fastest-growing fields in recent decades, as breakthroughs in technology have led to rapid advancements in computing, medical imaging,

telecommunications, fiber optics, and related fields.

Electrical engineers work with electricity in all its forms, from tiny electrons to large-scale magnetic fields. They apply scientific knowledge of electricity, magnetism, and light to solving problems that relate to cell phones, computer software, electronic music, radio and television broadcasting, air and space travel, and a wide range of other areas. According to the Institute of Electrical and Electronics Engineers, a background in electrical or computer engineering can lead to a career in aerospace, bioengineering, telecommunications, power, semiconductors, manufacturing, transportation, or related fields.
Electrical engineers often work in teams with other specialists to develop sophisticated devices such as lasers.

- ***Mechanical Engineering***
  Mechanical engineers turn energy into power and motion. What does that mean? "Anything that moves or uses power, there's a mechanical engineer involved in designing it," explains a member of this large branch of engineering.

  Mechanical engineers work in all areas of manufacturing, designing automobiles or sporting goods, water treatment facilities or ocean-going ships. In a field like biomechanics, their expertise can improve the quality of life by designing artificial joints or mechanical heart valves.

Other Engineering Disciplines

- ***Aeronautical and Aerospace Engineering***
  Aircraft, space vehicles, satellites, missiles, and rockets are some of the projects that are developed by aeronautical and aerospace engineers. They get involved in testing new materials, engines, body shapes, and structures that increase speed and strength of a flying vehicle.

  Aerospace engineers work in commercial aviation, national defense, and space exploration. Some engineers work in labs testing aircraft, while others investigate system failures such as crashes to determine the cause and prevent future accidents. They are specialists in fields such as aerodynamics, propulsion, navigation, flight-testing, and more.

  I have a close friend who is an Aeronautical Engineer. As he heads off to work he is always saying, “ I’m off to make a ridiculous amount of money to draw pictures of airplanes” There’s a lot more to being an engineer then just drawing pictures of airplanes, but you do get to draw a lot, and much of it is done on the computer.

- ***Agricultural Engineering***
  Agricultural engineers work with farmers, agricultural businesses, and conservation organizations to develop solutions to problems relating to the use and conservation of land,

rivers, and forests. They look for solutions to problems such as soil erosion. They also develop new ways of harvesting crops and improving livestock and crop production.

Agricultural engineers also design and build equipment, machinery, and buildings that are important in the production and processing of food, fiber, and timber. For example, they might design specialized greenhouses to protect and grow exotic plants such as orchids.

- ***Biomedical Engineering***
  Biomedical engineering integrates physical, chemical, mathematical, and computational sciences and engineering principles to study biology, medicine, behavior, and health. It advances fundamental concepts; creates knowledge from the molecular to the organ systems level; and develops innovative biologics, materials, processes, implants, devices and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health.

  Biomedical engineers, or bioengineers, use engineering principles to solve complex medical problems in health care and medical services. They work with doctors and medical scientists to develop and apply the latest technologies, such as microcomputers, electronics, and lasers.

  Biomedical engineers might develop biomaterials to speed tissue repair in burn victims, or design medical devices that aid doctors in surgery. They might help to build bionic legs, arms, or hands to improve the lives of accident victims.

  The biomedical field is changing rapidly as new technologies emerge. Bioengineers work in hospitals, government agencies, medical device companies, research labs, universities, and corporations. Many biomedical engineers have degrees in chemical or electrical engineering, and some go to medical school.

*Later, I will discuss in much more detail the field of biomedical engineering.

- ***Environmental Engineering***
  Environmental engineers develop methods to solve problems related to the environment. They assist with the development of water distribution systems, recycling methods, sewage treatment plants, and other pollution prevention and control systems. Environmental engineers often conduct hazardous-waste management evaluations to offer solutions for treatment and containment of hazardous waste. Environmental engineers work locally and globally. They study and attempt to minimize the effects of acid rain, global warming, automobile emissions, and ozone depletion.

- ***Industrial Engineering***
  Industrial engineers make things work better, more safely, and more economical. They often

work in manufacturing—dealing with design and management, quality control, and the human factors of engineering. They are problem-solvers who analyze and evaluate methods of production and ways to improve the methods. Based on their evaluation, they may determine how a company should allocate its resources.

- ***Materials Engineering***
  Materials engineers work with plastics, metals, ceramics, semiconductors, and composites to make products. They develop new materials from raw materials and improve upon existing materials. Whether it's creating higher performance skis or a biodegradable coffee cup, materials engineers can be found applying their expertise.

  Materials engineers specializing in metals are metallurgical engineers, while those specializing in ceramics are ceramic engineers. Metallurgical engineers extract and refine metals from ores, process metals into products, and improve upon metalworking processes. Ceramic engineers develop ceramic materials and the processes for making ceramic materials into useful products. Ceramic engineers work on products as diverse as glassware, automobile and aircraft engine components, fiber-optic communication lines, tile, and electric insulators.

- ***Mining Engineering***
  Mining engineers figure out how to get valuable resources out of the ground. Along with geologists, they locate, remove, and appraise minerals they find in the earth. Mining engineers plan, design, and operate profitable mines. They are also responsible for protecting and restoring the land during and after a mining project so that it may be used for other purposes.

- ***Nuclear Engineering***
  Nuclear engineers research and develop methods and instruments that use nuclear energy and radiation. They may work at nuclear power plants and be responsible for the safe disposal of nuclear waste. Some nuclear engineers specialize in the development of nuclear power for spacecraft; others find industrial and medical uses for radioactive materials, such as equipment to diagnose and treat medical problems.

- ***Petroleum Engineering***
  Petroleum engineers are found wherever there is oil, working to remove oil from the ground. Petroleum engineers might be involved in drilling or developing oil fields. They might also ensure that the oil drilling process is safe, economical, and environmentally friendly.

- ***Systems Engineering***
  Systems engineers are like team captains who are responsible for bringing all the pieces of an

engineering project together and making them work harmoniously, while still meeting performance and cost goals, and keeping on schedule. Systems engineering takes an interdisciplinary approach to a project, from concept to production to operation. Systems engineers consider both the business and technical needs of a project.

Biomedical Engineering

A Biomedical Engineer uses traditional engineering expertise to analyze and solve problems in biology and medicine, providing an overall enhancement of health care. Students choose the biomedical engineering field to be of service to people, to partake of the excitement of working with living systems, and to apply advanced technology to the complex problems of medical care. The biomedical engineer works with other health care professionals including physicians, nurses, therapists and technicians. Biomedical engineers may be called upon in a wide range of capacities: to design instruments devices, and software, to bring together knowledge from many technical sources to develop new procedures, or to conduct research needed to solve clinical problems.

In this field there is continual change and creation of new areas due to rapid advancement in biology and technology; however, some of the well established specialty areas within the field of biomedical engineering are: bioinstrumentation; biomaterials; biomechanics cellular, tissue and genetic engineering; clinical engineering; medical imaging; orthopedic surgery; rehabilitation engineering; and systems physiology.

Work done by biomedical engineers may include a wide range of activities such as: Artificial organs (hearing aids, cardiac pacemakers, artificial kidneys and hearts, blood oxygenators, synthetic blood vessels, joints, arms, and legs). Automated patient monitoring (during surgery or in intensive care, healthy persons in unusual environments, such as astronauts in space or underwater divers at great depth). Blood chemistry sensors (potassium, sodium, O_2, CO_2, and pH). Advanced therapeutic and surgical devices (laser system for eye surgery, automated delivery of insulin, etc.) Application of expert systems and artificial intelligence to clinical decision making (computer-based systems for diagnosing diseases). Design of optimal clinical laboratories (computerized analyzer for blood samples, Medical imaging systems (ultrasound, magnetic resonance, imaging etc.). Biomaterials design (mechanical, transport and biocompatibility properties of implantable artificial materials). Biomechanics of injury and wound healing (Sports medicine)

Orthopedic Bioengineering is the specialty where method of engineering and computational mechanics have been applied for the understanding of the function of bones, joints and muscles, and for the design of artificial joint replacements. Orthopedic bioengineers analyze the friction, lubrication and wear characteristics of natural and artificial joints; they perform stress analysis of the musculoskeletal system; and they develop artificial biomaterials (biologic and synthetic) for replacement of bones, cartilages, ligaments, tendons, meniscus and intervertebral discs. They often perform gait and motion analyses for sports performance and patient outcome following surgical procedures. Rehabilitation Engineering is a growing specialty area of biomedical engineering. Rehabilitation engineers enhance the capabilities and improve the quality of life for individuals with physical and cognitive impairments.

They are involved in prosthetics, the development of home, workplace and transportation modifications and the design of assistive technology that enhance seating and positioning, mobility, and communication. Rehabilitation engineers are also developing hardware and software computer adaptations and cognitive aids to assist people with cognitive difficulties.

Systems Physiology is the term used to describe that aspect of biomedical engineering in which engineering strategies, techniques and tools are used to gain a comprehensive and integrated understanding of the function of living organisms ranging from bacteria to humans. Computer modeling is used in the analysis of experimental data and in formulating mathematical descriptions of physiological events. In research, predictor models are used in designing new experiments to refine our knowledge. Living systems have highly regulated feedback control systems that can be examined with state-of-the-art techniques. Examples are the biochemistry of metabolism and the control of limb movements. These specialty areas frequently depend on each other. Often, the biomedical engineer who works in an applied field will use knowledge gathered by biomedical engineers working in other areas. For example, the design of an artificial hip is greatly aided by studies on anatomy, bone biomechanics, gait analysis, and biomaterial compatibility. The forces that are applied to the hip can be considered in the design and material selection for the prosthesis. Similarly, the design of systems to electrically stimulate paralyzed muscle to move in a controlled way uses knowledge of the behavior of the human musculoskeletal system. The selection of appropriate materials used in these devices falls within the realm of the biomaterials engineer.

Where Do Biomedical Engineers Work?

Biomedical engineers are employed in universities, industry, in hospitals, in research facilities of educational and medical institutions, in teaching, and in government regulatory agencies. In industry, they may create designs where an in-depth understanding of living systems and of technology is essential. They may be involved in performance testing of new or proposed products. Government positions often involve product testing and safety, as well as establishing safety standards for devices. In the hospital, the biomedical engineer may provide advice on the selection and use of medical equipment, as well as supervising its performance testing and maintenance. They may also build customized devices for special health care or research needs. In research institutions, biomedical engineers supervise laboratories and equipment, and participate in or direct research activities in collaboration with other researchers with such backgrounds as medicine, physiology, and nursing. Some biomedical engineers are technical advisors for marketing departments of companies and some are in management positions. Some biomedical engineers also have advanced training in other fields. For example, many biomedical engineers also have an M.D. degree, there by combining an understanding of advanced technology with direct patient care or clinical research.

Biomedical engineers play a significant role in mapping the human genome, robotics, tissue engineering, and in nano technology. Biomedical engineering has the highest percentage of female students in all of the engineering specialties. 30% of biomedical engineering graduates are employed in manufacturing. Many biomedical engineering graduates go on to medical school. The percentage of students applying to medical school is as high as 50% in some programs.

Biomedical engineering has 38 female students at the undergraduate level (slightly lower at the graduate level). This is double the average for engineering as a whole. (19-20% female).

Appendix B: Women and Engineering

Women's Participation in Science, Engineering, and Technology—Current Statistics (Intel innovation in Education)

Although women have increased their participation in science, engineering, and technology, they still comprise only 19% of the U.S. science, engineering, and technology workforce[1]. While women in the U.S earn 20% of engineering degrees, only 10.6% of American engineers are women[2]. Further, the percentage of women graduating with computer science degrees has decreased 25% since 1985[3]. Inequity causes serious problems for individual students and for our increasingly technological society—the talent and creativity of each individual is vital to the future of the global community.

Classroom Environment Counts

Classroom environment makes a difference as well. A positive classroom climate, supportive students, diverse role models, and even the right pictures on the walls in the room can help to keep girls (and boys) in math and science courses.

Research, summarized in the AAUW Report: *How Schools Shortchange Girls* found:

• Girls are more successful in classes in which there is fairness and equitable treatment.

• Girls who see math as what girls and boys do, are more apt to go on in math and do better in it than are girls who see math as a “boy thing.”

• Getting more girls into advanced math and science classes makes a difference. When there are only a small number of girls, girls report feeling more intimidated and less comfortable. Close to equal numbers of girls and boys means increased confidence for many girls and reinforces that math and science are for girls as well as boys.

What Can Elementary School Teachers Do?

Believe it or not, teachers really are important influences in students’ lives. In 1987 Campbell and Metz studied female engineering students and found math and science teachers, along with parents, were the girls’ most effective encouragers. Furthermore, studies have found that the students who overcome what the research calls “devastated backgrounds” tend to have one thing in common — a caring adult outside of the family who is “on their side.”
Most frequently that adult is a teacher. Teachers make a lifelong difference. Your encouragement counts a great deal. A little bit of effort in the organizing of lessons, and science curriculum reflecting girls interest will reap huge benefits in their productivity. Reading books on famous scientists and engineers could encourage women to consider engineering as a potential career.

The Crucial Middle School Years

The middle school years are crucial for girls who may have enjoyed science and technology in elementary school. By the eighth grade, twice as many boys as girls show an interest in science, engineering, and mathematics careers[4]. Additionally, fewer girls than boys enroll in computer science classes, feel self-confident with computers, and use computers outside the classroom[5]. Lastly, at all levels of education and in employment, women are less likely than men to choose science and engineering fields[6]. When girls lose interest in science and math early on, they often neglect to take the higher-level math and science courses—"gatekeeper" courses—in high school. Their educational and career options are then drastically reduced.

Supportive Environments for Learning Science and Engineering

In the last decade, a wealth of research has investigated why girls tend to lose enthusiasm for science, mathematics, and technology, starting in the middle grades. Additional research has focused on the learning environments that encourage girls' curiosity and interest in these fields. Importantly, environments that support girls' science learning also support all students. The factors that research has shown to have a positive impact on girls' (and all students) continuing involvement with science and technology include[7]:

- Interactive, collaborative, and team-based environments that offer the opportunity to work on real-world problems. Girls typically enjoy solving problems that are socially relevant and meaningful. They may enjoy collaboration within the context of competitions.
- Exploratory environments that say it's OK to ask questions, take risks, and make mistakes. Single-sex groups may bolster girls' performance in mathematics and science, and be particularly applicable for after-school science programs.
- Role models: Teachers, group leaders, and mentors in the fields of science, engineering, and technology who understand gender-equitable instruction; provide encouragement and support of non-traditional occupations for women, and actively challenge stereotypes about women in science, engineering, and technology.
- Hands-on, inquiry-based activities to foster knowledge, skill development, experimentation, and creativity in the areas of science, engineering, and technology. Inquiry-based instructional approaches place students at the helm of the learning process and teachers in the role of learning facilitator, coach, and modeler. Skill development leads to competence and self-confidence.
- Gender-neutral career counseling that encourages girls to take four years of math and science in high school. Upper level science and mathematics courses are the "gatekeeper" courses that open doors after high school.
- Career exploration through real-world science and technology experiences including after-school science programs, field trips, conferences, science fairs, and internships. Real-world experiences provide awareness of career opportunities in the fields of science, engineering, and technology.

An excerpt from a report from the Girl Scout Research Institute states, "The research implies that technology and the prevalent culture would be transformed if the strengths and interests in computers of girls and women were given greater consideration. Awareness of the ways to provide increased pathways for girls to enter into the design and utilization of technology can only enhance the field."

Appendix C: Technology and Gender

Myth from Fact on Gender

What is the current mythology about girls and technology?

What does the most recent research tell us? Can we separate myth from fact? Research findings short-circuit the myths dramatically, as the following examples show:

MYTH: Girls have little interest or aptitude in technology.

FACT: Currently, girls are highly engaged with computers and their usage has increased steadily over time, on par with that of boys. The percentage of students using computers at home or in school more than doubled between 1984 (30 percent) and 1997 (80 percent), with no gender differences in the rates of use in either year.

Source: National Center for Education Statistics (2000)

MYTH: All of us, female and male alike, use technology similarly.

FACT: Girls use computers in ways very different from boys. In an analysis of technological fantasies, researchers summarized some of the most striking differences in how girls and boys think about technology. Even in their Internet use, girls emphasize educational and communicative functions, while boys tend to use computers more for entertainment and recreational purposes. Girls use technology as a tool of empowerment, sharing, creation, and expressiveness. Boys use it in ways related to control, power, and autonomy.

Source: *Girl Games and Technological Desir*e.C. Bruner, D. Bennett, and M. Honey (1998)

MYTH: Boys have greater access to computers than girls.

FACT: Girls are using computers as often as boys. The amount of time girls and boys spend at the computer or on the Internet is essentially equal.

Source: *Safe and Smart: Research and Guidelines for Children's Use of the Interne*t. National School Boards Foundation (2000).

MYTH: Gender-neutral software, beneficial to the technology styles and interests of both girls and boys, is universally available and prevails in the market.

FACT: Almost half of the top-selling video games with female characters contain negative messages about girls, including violence, unrealistic body images, and stereotypical female characteristics (e.g., provocative sexuality, high-pitched voices, and fainting).

Source: *Girls and Gaming: A Console Video Game Content Analysi*s. Children Now (2000).

"We should also focus on incorporating a female perspective in designing software and programs. Why is there a Game Boy and not a Game Girl? Girls have different interests and needs than boys and their perspective needs to be represented in the design process.

—Linda M. Sherr, program director, IBM Women in Technology creation, and expressiveness. Boys use it in ways related to control, power, and autonomy.

Source: *Girl Games and Technological Desir*e. C. Bruner, D. Bennett, and M. Honey (1998)

MYTH*:* Computer and Internet use will have more harmful effects than beneficial ones.

FACT: Research indicates that, although young people's use of technology has become routine practice, they spend less time watching television; more time reading newspapers, magazines, and books; more time interacting with family and friends; more time playing outdoors; and more time doing arts and crafts than they did before computers became widely available.

Source: *Safe and Smart: Research and Guidelines for Children's Use of the Internet* . National School Boards Foundation (2000)

MYTH: Technology has become the great social leveler. All children, regardless of race/ethnicity or socioeconomic status, now have equal access to technology because schools and libraries have provided computers universally.

FACT: Differences in computer usage are mainly economic, not racial or ethnic. Racial differences can, by and large, be explained by examining income level. School and library availability does not level the playing field. Young people use computers more at home than in school or at other sites.

Girls and boys become proficient because they have open access to computers at home. There appear to be no racial or ethnic differences in the amount of home use, except those that are determined by the socioeconomic level of the family.

Source: *Kids and Media @ the New Millenniu*m. The Henry J. Kaiser Family Foundation (1999)

MYTH: Increased use of technology by girls has led to increased career choices and opportunities in the field of information technology.

FACT: Girls' increasing use of technology is not mirrored in their adult academic or economic pursuits in these arenas.

MYTH*:* Technology achievement is more natural for men than for women.

FACT: People with liberal arts degrees, specialized training, and critical thinking skills can fill up to 80 percent of information technology jobs. Girls' strengths in reading and writing, combined with their current use of technology for communication and social functions, provides an entrée to teach girls more technical skills.

Research suggests we can work toward re-visioning technology so that it incorporates and builds on perspectives and values girls bring to it rather than focusing on how we can help girls adapt to the predominantly male world of technology.

Source: National Science Foundation, 1999 *"Currently, much of the software designed for children is geared toward boys. Not surprisingly, many software game designers are men. We need women and girls to be part of the equation."*

Linda M. Sherr, program director, IBM Women in Technology

MYTH: Girls today have strong women role models in science and technology. They are finding their way into careers in those fields in increasing numbers.

FACT: Even girls with strong skills in math, science, and technology do not pursue careers in those areas. This may occur because they do not have women to mentor them into the field, and because they find the male-defined environments stylistically unaccommodating to women.

"The key is to identify girls' interests at an early age, provide them with the opportunities to learn about math, science, and technology, and link them together in a support network to keep them motivated." Sally Ride, Astronaut, NASA

Appendix D: WASL Conclusions

1. Conclusive statement that correctly answers the investigative question.

As the ____________________ _______________ ,

(manipulated variable) (increased, decreased)

the ______________ _______________________.

(responding variable) (increased, decreased, stayed the same)

Examples:

- As the angle of the ramp increased, the average speed of the car increased.
- As the enzyme concentration increased, the rate of reaction increased.
- As the depth of the lake increased, the temperature of the lake decreased.
- As the altitude increased, the pressure decreased

2. Supporting Data- Both Lowest and Highest

When the ________________ was, ____________

(manipulated variable) X (lowest)

the __________________was ______.

(responding variable) (X)

When the ________________ was, ____________

(manipulated variable) X (highest)

the __________________was ______.

(responding variable) (X)

- At an angle of 5 degrees, the average speed of the car was 20 cm/s. At an angle of 20 degrees, the average speed of the car was 50 cm/s.

- At an enzyme concentration of 25% the rate of the reaction was 10 s. At an enzyme concentration of 100% the rate of the reaction sped up to 2 s.
- At a depth of 2 meters, the temperature of the lake was 45 degrees Celsius. At a depth of 20 meters the temperature of the lake was 30 degrees Celsius.

3. Explanation- Connect the support data to the conclusion.

Use comparative language. (Fastest, faster, highest, higher, slower, greatest, etc). to summarize the relationship between the manipulated and responding variable.

- At 5 degrees, which was the smallest ramp angle, the average speed of the car was slowest, while at the steepest ramp angle the average speed of the car was fastest, confirming that as ramp angles increase, the average speed of the car increases.
- The data shows that the highest concentration of enzyme (100%) had the fastest rate of reaction, while the lowest concentration of enzyme (25%) had the slowest rate of reaction, confirming that increasing the concentration of enzyme increasing the rate of reaction.

WASL CONCLUSIONS

As the ____________________ _______________ ,

(manipulated variable) (increased, decreased)

the ______________ _______________________.

(responding variable) (increased, decreased, stayed the same)

When the ________________ was, ____________

(manipulated variable) X (lowest)

the __________________was ______.

(responding variable) (X)

When the ________________ was, ____________

(manipulated variable) X (highest)

the __________________was ______.

(responding variable) (X)

When the ________________ was, ____________

(manipulated variable) (comparative word)

the __________________was _________________.

(responding variable) (comparative word)

When the ________________ was, ____________

(manipulated variable) (comparative word)

the __________________was _______________.

(responding variable) (comparative word)

Appendix E: Sources

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