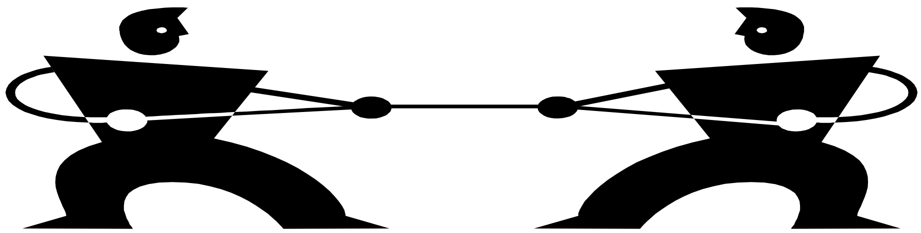
TEACHER INFORMATION

“Can you handle the stress?”



“Are you under too much strain?”

A lesson on the mechanical properties of materials and the determination of the Young’s Modulus.

Anticipatory Set:

When the students arrive in class, they will see a board resting on two chairs. The teacher will begin the lesson by standing on the middle of the board. The fundamental question that is asked of the students is ***“why does the board bend?”*** Once students have brainstormed on that question, the teacher will also ask, ***“what can we do to make it bend less or more?”*** This will hopefully lead right into discussions of the terminology for this activity and what measurements to make. Teachers may also find it useful to bring up these other questions, ***“does it matter what material I am standing upon?”*** and ***“does it matter what orientation the board has?”***. Any questions that will bring about discussion amongst the students is useful and will help promote the lesson. The teacher should spend about **5 to 10 minutes** on this introduction.

Input:

Next, the teacher should present the activity. The activity is designed to be open-ended for the students, so they really need to think about how to accomplish the goals without a large amount of guidance. This will hopefully give the students a better understanding of what it means to “do science”. The teacher should hand out the activity sheet and introduce the purpose of the activity.

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

Purpose: To determine the Young's modulus for four different materials in two different ways and compare the stiffness of the materials based upon this value.

This will require the students to have an understanding of the terminology involved. Allow the students to read over the background on elasticity given on their activity sheet. The teacher should then go over the major terms and equations. All of this input and reading should take about **10 to 15 minutes**.

Background on Elasticity Terminology and Equations:

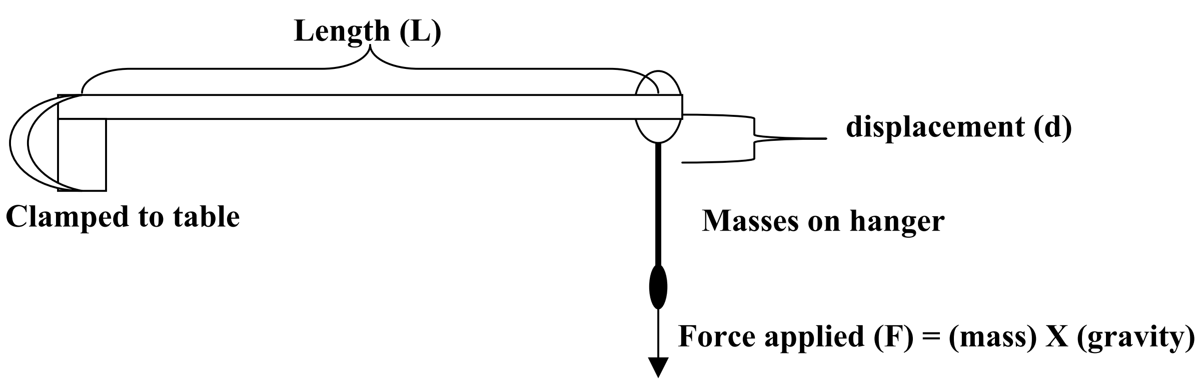
- **Stiffness:** a measure of the amount of stress needed to bend the material.
- **Strength:** a measure of the amount of stress on a material before breaking.
- **Yield:** the stress point beyond which the material will not return to its original shape.
- **Stress (σ):** a measure of the force applied divided by the cross-sectional area of the material. $\sigma = F / A$
- **Strain (ε):** a measure of the ratio of the elongation of the material to its original length. $\varepsilon = \Delta l / lo$
- **Young's modulus (E):** a measure of the ratio of the stress on a material to the strain. $E = \sigma / \varepsilon$
  - **2-point testing**
    - One end of the material is clamped down while force is applied to the other end.
    - Relationship between displacement of the material and the force applied.
    - $d = 4FL^3 / Ewh^3$
  - **3-point testing**
    - Material rests upon two supports with the force applied to the middle of the material
    - Relationship between displacement of the material and the force applied.
    - $d = FL^3 / 4Ewh^3$

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

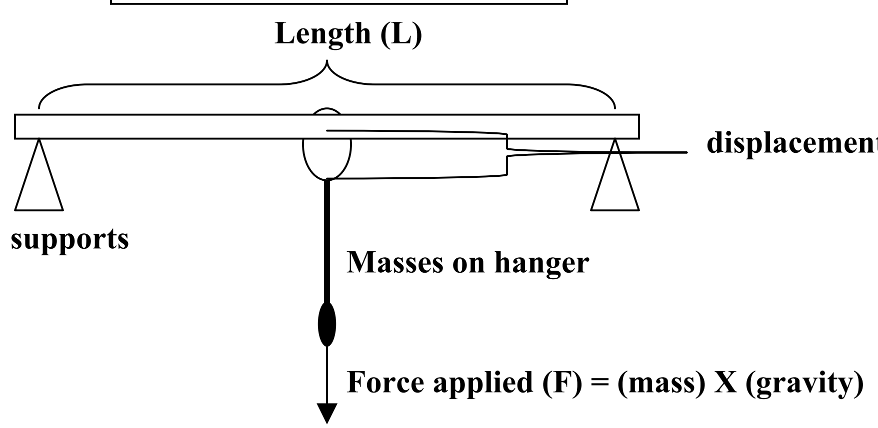
Modeling:

Here is where the teacher will demonstrate the set up for the activity. The students will be performing 2-point and 3-point test of four different materials. They will make a series of measurements at different amounts of force so that they can plot the displacement of the materials versus the force applied. From the graph and their measurements, they can determine the **Young's modulus** for each of the materials and be able to make statements about the stiffness of the materials. Here are some pictures showing what the set up will look like and what measurements the students will be making. The teacher can also have sample graphs so that when students get to that part of the activity, they have a suggested model to follow. It should take the teacher about **5 to 10 minutes** to model the set ups.

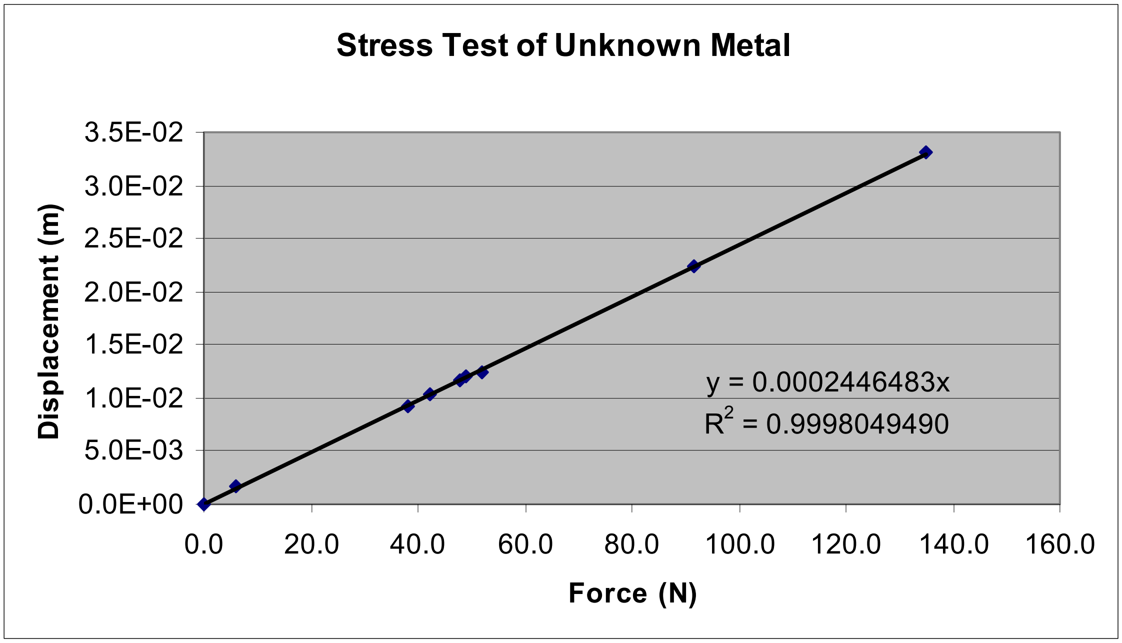
2-point test set up



3-point test set up



Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992



Sample Graph

Guided Practice:

The teacher will divide the class into groups of four. At this point, it would be good for the groups to make measurements of their materials with the vernier calipers. Since all of the materials should be about the same, the teacher can make sure that the students are in the right range before moving on. The teacher can also have the students set up for a 2-point test. Before having the students begin applying forces, the teacher should go around and make sure the set ups will work. The teacher should only make suggestions on improvements and allow the students to determine the appropriate changes. The teacher should guide them in the beginning **15 to 30 minutes** of the groups working.

Checking For Understanding:

The teacher should walk around the room while the students are working and watch what each group does. This is a great time to ask questions about their set up to determine whether they understand what measurements to make and whether they are gathering the correct data.

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

Independent Practice:

The groups are on their own to determine how many measurements to make and getting the 3-point test set up. The groups will also need to remember how to make a graph of their data and how to manipulate the information from the graph with the equations provided to determine the Young's modulus. The groups are also on their own in calculating the percent error between their values and the accepted values. The students should be allowed to work for the remainder of the time on the activity. This should take about **30 to 50 minutes.**

Closure:

The groups will be presenting their findings in a graphical format as well as making calculations of the percent error of these findings. The teacher can grade the students on their graphs and the results they obtained in their analysis of the data.

Equipment:

Steel beam	**Meter stick**
Copper beam	**Vernier Caliper**
Garolite (fiberglass) beam	**Various Slotted Masses (100 g to 5000 g)**
Balsa wood beam	**Mass Hanger**
C Clamp	**Wire**
2" X 4" X 6' board	**Chairs (2)**

Assessment:

The students will be doing the following as an assessment of their understanding of the activity.

Graphs:

- Make a graph of **displacement of the material (d)** on the y-axis and the **force applied to the material (F)** on the x-axis.
- Draw a best fit line through the points and determine the slope of the line.
- Using the slope of the line and the equations given for the 2-point and 3-point tests, determine the **Young's modulus** for each of the materials.

Analysis:

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

- Rank your materials from most stiff to least stiff based upon your value for the **Young's modulus** for each.
- Calculate the percent error for each of your materials using the accepted value of the Young's modulus for each below.

Material	Young's modulus (N / m^2)
Steel	19.2×10^{10}
Copper	12.5×10^{10}
Garolite (fiberglass)	1.70×10^{10}
Balsa wood	0.0150×10^{10}

Both the graphs and the analysis should be graded to determine how well the groups understood the activity. The following rubrics for the graphs and the analysis are designed to aid the teacher in grading, but can be modified as need be. The following rubrics are designed on a 0 - 4 scale, but could be weighted differently based upon how much emphasis the teacher wishes to place on each part of the assessment. It would also be beneficial for the students to see these rubrics before completing their assessment.

Graph Rubric:

Group's Score	Criteria
4	Graphs are complete with everything labeled, slopes, and determination of the Young's modulus
3	Graphs are mostly complete with no more than one of the following missing: labels, slopes or Young's modulus
2	Graphs are incomplete with parts of more than one of the following missing: labels, slopes or Young's modulus
1	Graphs are incomplete with all of one or more of the following missing: labels, slopes or Young's modulus
0	No graphs are completed

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

Analysis Rubric:

Group's Score	Criteria
4	Analysis is complete with correct ranking of materials and correct calculation of the percent error
3	Analysis is mostly complete with no more than one of the following incorrect: ranking of materials and percent error
2	Analysis is incomplete with parts of more than one of the following missing and/or incorrect: ranking of materials and percent error
1	Analysis is incomplete with multiple parts missing and/or incorrect in terms of ranking of materials and percent error
0	No analysis is completed

Extensions:

The following extensions are possible things to do during class or to have students work on outside of class as extra credit or projects.

- Devise an experiment to determine Young's modulus and yield strength for different metal wires.
- Have students bring in materials from home to be tested.
- Have students test unknown materials and use the Young's modulus to identify them.
- Devise an experiment to test a material with different shapes other than a rectangular beam, such as a rod or a hollow material to prove Young's modulus remains the same.

Modifications:

The following modifications are suggestions for the teacher in case the lesson as written is either too long or too difficult for the students. It is suggested that the teacher run through the experiment and determine what works well and what would need modifying.

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

- The estimated time for the lesson is a single 80-minute class or two 50-minute classes. Ways to decrease time:
    - Give each group less materials to test and share with entire class.
    - Use equations directly with the measurements instead of graphing.
- The lesson is designed to be very open-ended without a lot of structure. The teacher can add in more structure to the procedure if needed.

Illinois State Science Standards Covered:

This lesson was developed with the Illinois State Science Standards in mind. It should cover other state's standards in science as well. It covers the following standards:

- 11.A Know and apply the concepts, principles and processes of scientific inquiry
- 12.C Know and apply concepts that describe properties of matter and energy and the interactions between them
- 12.D Know and apply concepts that describe force and motion and the principles that explain them
- 13.A Know and apply the accepted practices of science

Summary:

This lesson is designed to be very open-ended, allowing for the students to problem solve with some help from the teacher in determining how to accomplish the purpose and develop the materials needed for their group to be assessed. This activity will incorporate scientific method skills, graphing skills, and mathematical skills. It will cover the concept of mechanical properties of materials in determining their stiffness using a calculation of the Young's modulus. It will also involve the use of force and measurements that closely relate with Hooke's Law, which deals mostly with springs. It will be for general physics classes at the junior or senior level. The lesson is designed to fit into either a single 80-minute class period or two 50-minute class periods.

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992

Resources:

White, Harvey et al., Physics – An Experimental Science, D. Van Nostrand Company Inc., copyright 1968, pages 195 – 205.

Dissemination of IT for the Promotion of Materials Science (DoITPoMS), Department of Materials Science and Metallurgy, University of Cambridge, http://www.doitpoms.ac.uk/index.html

MatTER (Materials Teaching Educational Resources) Initiative for Schools, http://schools.matter.org.uk/

An Introduction to Metallic Materials, William F. Gale, Auburn University, Materials Research and Education Center, http://www.eng.auburn.edu/~wfgale/intro_metals/index.htm

http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/stiffness-density/NS6Chart.html

Acknowledgements:

Belleville Township High School East

Mr. John Sinnott and the Cornell University Materials Facility

2004 RET I Team consisting of Eric Bowerman, Dan Delorme, Ray Kaschalk, and Tracy Suggs

Kevin Dilley, Nev Singhota and the Cornell Center for Materials Research

Dr. Nell Ann Hennon

Support for Cornell Center for Materials Research is provided through NSF Grant DMR-0079992