Module Title: Metal Properties and Failure Experiment- The Paper Clip		
Lab compiled by: Tom Stoebe, MatEd Partner	Address:	Email: tgstoebe@earthlink.net

Time to complete module:

As an introductory exercise:

- 15 minutes for one paper clip per student for a 30 student class
- 45 minutes for several paper clips per student

For more Advanced classes:

- 20 minutes for 2 types of paper clip per student with full discussion
- 30 minutes for 2 steel clips and 1 plastic clip with discussion of differences

Description of module, lab or demonstration:

Students will explore several mechanisms for failure in metals through this simple in-class activity. Utilizing standard paper clips, students will stress via bending the paper clip and make observations throughout the loading process until failure occurs. With the aid of an assortment of paper clips, students will be able to investigate the effects of various processing methods, the variation in mechanical properties between similar alloys, and the various mechanisms for failure.

Pre-requisite knowledge and skills:

Although it may be beneficial if students have some knowledge of the processing of metals, alloy compositions, and fatigue- it is not necessary to carry out an effective in-class activity

Materials Category:		
	Structure of Materials	❒
	Metals	☑
	Ceramics	❒
	Polymers	❒
	Composites	❒
	Other	❒

Target Grade Level(s) (Check all that apply)		
	Middle School 6-8	☑
	High School 9-12	☑
	Two-year College 13-14	☑
	Four-year College 15-16	❒

MatEd core competencies that the training meets:

- 7.001 Describe the general nature of ferrous metals
- 16.007 Describe how changes in manufacturing process effect material properties

List of equipment and supplies needed:

In order to complete the simple introductory exercise one box of standard paper clips should be sufficient for the entire class; however for a more advanced activity:

<table>
<tr><td colspan="2">

Box of standard steel paper clips (or if available 2 boxes: 1 each of two different brands)
Jumbo steel paper clips (1 box each of two different bands if possible)
1 Box of serrated paper clips, if available
1 Box of brass or copper paper clips, if available
Plastic paper clips, congruent to metallic paper clips, if available
Chalkboard or White board for recording data
30- safety glasses (PPE)

</td></tr>
<tr><td>Curriculum overview and notes to instructor:</td><td>Bending a metal, as in this exercise, adds defects to the material. As defects accumulate, the metal gets harder and stronger and thus, more difficult to bend. Cracks form, leading to a fatigue failure. It needs to be emphasized that failure occurs because the metal actually gets stronger as it is bent. An incorrect perception is that the metal gets weaker under these circumstances, causing failure. This is never true. Bending also puts energy into the material, causing it to get warmer. In this experiment, typically the 180 degree bend breaks the paper clip in less than half the number of bends due to the greater stress on the bending point. If serrated paper clips are available, the serrations give a point for cracks to start, so the clips will typically break sooner. Differences seen between clips and between brands are usually due to differences in manufacturing and differences in the composition of the starting material.

Brass or copper paper clips will behave similarly to steels with different number of bends. Plastic paperclips will behave differently since the mode of failure will be different, as a result of the different structure of the plastic material.</td></tr>
<tr><td colspan="2">Mode of presentation: Laboratory</td></tr>
<tr><td>Module</td><td>Module Abstract:
This experiment introduces students to the properties of metals when they are deformed. In particular, paper clips are bent in a controlled manner until failure. This type of failure under repeated stress is called "fatigue" and the fatigue properties of different materials varies with material quality, material source, type of stress and duration of stress. Since paper clips are not high tech materials, they are usually made from cheap steels which have little strength and where variability of quality is not important. Some paper clips have serrations, which will hasten failure as they provide locations for cracks to propagate. In this experiment the student can experience fatigue and by comparing different types and sizes of paper</td></tr>
</table>

	clips, can develop a simple understanding of the relationship between metal failure, design variables, and processing variables of materials. **Process: Experiment 1** 1. Each student is given two standard paper clips of each type (for middle school grades, using jumbo paper clips is perhaps better as the students can hold the larger clips more easily) 2. Instruct students to take one paper clip and to open it up to resemble an "S" 3. Demonstrate to the students the means for bending to **90 degrees** 4. Ask the students to bend the paper clip as demonstrated and to count how many times it can be bent before the paper clip breaks. Count each full cycle (up and back) as one bend. 5. Collect the data and draw a histogram of the results. That is a histogram of number to bends to failure vs. number of students with each result. 6. Ask if the paper clip got more difficult to bend as the number of bends increased. Have the class discuss why this might be the case. Ask if this is what caused the breakage? 7. Did the paper clip get warmer during bending? What does this indicate? 8. Discuss the differences noted. Ask for ideas as to why there is such a variation between paper clips. If needed, suggest • Speed of bending • Quality of Steel • Defects in the metal 9. Repeat the experiment using the second standard paper clip • This time have the students bend the paper clip **180 degrees** • Draw the histogram and discuss the differences 10. Discuss what these results mean in terms of • Why there is so much variability between clips and between bending modes • Effect of bending stress (90 vs. 180 degrees) on the failure • Possible effect due to variations in metal processing • Possible effects due to variations in quality of the steel

	Process: Experiment 2 1. Repeat the process with serrated paper clips. Compare to the results of Experiment 1 using a histogram to compare 2. Discuss the differences observed: • What effect do the serrations have? Why? • What does this mean in terms of the influence of defects on metal properties? 3. Repeat the process if paper clips of different materials and different sizes, if available. 4. Complete the experiment by discussing • Possible causes of differences observed between different materials • How could one standardize the materials to reduce variability? • This is an example of accelerated life testing, used by engineers to determine how much stress a material can withstand. Why would engineers do this? **Further Study:** 1. Further compare paper clips (i.e. compare standard paper clips to the jumbo paper clips) 2. Utilize the internet to research fatigue in metals 3. Find typical composition of steels used in the manufacturing of paper clips. 4. Research possible causes of differences observed between different materials.
References:	Hunkin's Experiments. (August 2006). *Paper clips*. Retrieved August 20, 2007 from, http://www.hunkinsexperiments.com/pages/paperclips.htm Schneider, J. (August 2007). *Flying paper clips*. Retrieved August 20, 2007 from, http://www.lessonplanspage.com/ScienceExCanAPaperClipFloatInAirMO68.htm Lienhard, J.H. (1997). *The paper clip*. Retrieved August 20, 2007 from http://www.uh.edu/engines/epi769.htm ReliaSoft Corporation. (2007). *Paper clip example*. Retrieved August 20, 2007 from, http://www.weibull.com/AccelTestWeb/paper_clip_example.htm

Briefly describe how the effectiveness of the module was evaluated:	"10 Simple and Effective In-class Experiments and Demonstration for Materials Education, An Overview" - Ryan A. Webster, Intern-Edmonds Community College
Author Bio:	Dr. Tom Stoebe works with the National Resource Center for Materials Technology Education (MatEd) housed at Edmonds Community College. Dr. Stoebe is a Professor Emeritus in Materials Science and Engineering at the University of Washington and has been at the forefront of materials education in the United States.