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Games: Glass and Materials Science to Engage Students

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<u>GaMES: Glass and Materials Science to Engage Students</u>

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Abstract

Materials science is the study of the properties of matter and its applications in optics, chemistry, physics, and civil, electrical, chemical, and mechanical engineering. The broad field of materials science and the complex ideas that can be included in it are typically introduced into formal education at the college level, but recently there has been a push for younger students to also have exposure to materials science. In this project, we used the techniques demonstrated in First Physics to expose students, ages 9-15, to materials science. Our hypothesis was that by using these techniques, higher level concepts can be broken into parts which can be easily learned by younger students through an inquiry-based approach. Questions being asked were: (1) At what age can students learn and apply skills such as modeling instruction? (2) Which pedagogical technique(s) proved most successful? (3) How can we develop a metric for success? To investigate this, our group has designed, built, and implemented a week long summer materials science outreach program. Students for this were selected from local middle and high schools and from underrepresented and minority groups (28 students). In order to measure the progress of the project and demonstrate success, the students were given a questionnaire before and after the camp. We also tracked involvement and growth throughout the camp via observation. Hopefully students from this program have obtained an introduction to fundamental materials science necessary to open their options to, or increase interest in, STEM careers.

I. Introduction & Background

Researchers believe by exposing physics to ninth graders you can enhance a student's relationship to the discipline of science. By using Modeling Instruction, an inquiry-based approach, students design and perform experiments to investigate relationships even before these relationships are explicitly identified in a lecture. One such method is an inverted high school science sequence known as Physics First. Techniques like Physics First enable the students to develop their own understanding through interpretations of data they have collected. This approach has been shown to be a successful method of teaching as it helps to develop skills such as proportional reasoning, mathematical modeling, and using empirical evidence in problem solving which have many functions even outside the classroom[1]. Physics introduced at the junior or senior year is more likely to subject to strict curriculum requirements set by standardized tests and to focus on pencil-on-paper problem solving which can overemphasize mathematical applications, and in the process obscure physics concepts[1-3]. By removing much of the mathematics from a physics course, teachers and students are able to rely more on important conceptual understanding, and building models of physical phenomena up from empirical observations. Even without focusing on the pen and paper problem solving through mathematics it has been shown that by exposing students to mathematical tools through the lens of physics can help teach math [2,3].

In this proposed project, we will utilize the pedagogical techniques demonstrated in the Physics First program in order to expose and engage middle school students to concepts in materials science. Our hypothesis is that by using these techniques higher level concepts, such as those previously discussed, can be broken into parts which can be easily learned by younger students through an inquiry-based approach. Questions being asked are: (1) At what age can students learn and apply skills such as modeling instruction? (2) Which pedagogical technique(s) proved most successful in teaching upper level concepts? (3) How can we develop a metric for success?

In order to test our hypothesis, our group will design, build, and implement a 1 week materials science summer outreach program, aimed at local middle school students. We had 28 kids register for this program in contradiction with the 20 or less we had expected. We were responsible for determining how each day would be spent, what other supplies would be needed in addition to the Materials Science Kits, what other demonstrations and activities could be done, where the activities would take place/organization and booking of campus rooms and laboratories, and working with other Ursinus college faculty to introduce students to a variety of materials related research. It is our goal that once this program is established it can be easily passed down to other undergraduate students at little to no additional cost.

During the summer program, we taught materials science to a select group of local middle and high school students through hands on activities and demonstrations as well as short courses. The students will use our laboratory facilities and work through activities directly from the Materials Science Kits guided by advanced undergraduate students. Students also worked in real research laboratories and met professors and students working on current research related to materials and glass science.

In order to measure the progress of the project and demonstrate success, the students were given a questionnaire before and after the camp. This questionnaire included questions relating to common problems in materials and glass science and will demonstrate their general knowledge. We will also ask them about their career and academic goals after high school. The post camp test will test their knowledge gained during the week. The post camp test will also ask the student if their after high school goals or outlook has changed. Observations will be made throughout the camp experience which will help in our analysis of which concepts were learned and by what method. Hopefully students from this program will obtain the introduction and fundamental science knowledge necessary to open their options to careers in STEM, and to enhance their overall science experience and understanding of the world around them.

II. Camp Design

In this section we present the daily schedule for the camp. Each day focussed on a different topic with supporting activities.

Engineering and Material Strength Day (Monday June 24th):

Topics covered: Engineering, composite materials, characterization
Students will test material strength.
Day Schedule:
9am - 9:30am Drop Off, Check-In (Room IDC 116)
9:30am - 10am Introductions, notebooks, T-Shirts, beginning of camp survey
10am – 10:30am What is a composite material? How do we measure material strength? (Room IDC 116)
10:30am – 11:30am (Slides) Lab: How Strong is your Chocolate? (Room IDC 116)
11:30am – 12:30pm Lunch provided (60 mins, Pizza, IDC 116)
12:30pm – 3:00pm (Slides) Lab: Engineered Concrete I. (Day 1) (Room PF 314)
3pm – 5pm (Aftercare, Check Out in Room IDC 116)

Engineering and Material Strength Day (Tuesday, June 25th):

Topics covered: Engineering, composite materials, characterization
Day Schedule:
9am - 9:30am Drop Off, Check-In (Room IDC 116)
9:30am - 10am Material properties, minerals (Room IDC 116)
10:00am – 12:00pm (Slides) Mineral Lab
12:00pm – 12:30pm Lunch (Students bring lunch) (30 mins, Room IDC 116)
12:30pm – 1:30pm Lab: Thermal Shock
1:30pm – 3:00pm Lab: Engineered Concrete II. (Day 2)
3pm – 5pm (Aftercare, Check Out in Room IDC 116)

Glass Day (Wednesday June 26th):

Topics covered: Engineering, optics, bridging art & science
Day Schedule:
9am - 9:30am Drop Off, Check-In (Room IDC 116)
9:30am – 10:00am What is glass and why is it important? (Room IDC 116)
10am – 11:30am (Slides) Lab: Candy Pull (Room PF 314)
11:30am – 12:30pm Lunch provided (60 mins, Hogies, Room PF 116)
12:30pm – 2:30pm Lab: Glass Bead on a Wire (Room PF 314)
(*Thermal Shock*) (PF 314)

2:30pm – 3pm How is glass/composite materials used around campus? In your daily life? (Ursinus Campus)
3pm – 5pm (Aftercare, Check Out in Room IDC 116)

<u>Polymer Day (Thursday, June 27th):</u>

Guest Speaker – Dr. Samantha Wilner, Chemistry Dept.
Topics covered: Polymer science, engineering, bridging art & science, applications
<u>Day Schedule</u>:
9am - 9:30am Drop Off, Check-In (Room IDC 116)
9:30am - 10am (Slides) What is a polymer and why is it important, how can it be used? Crosslinking. Phases of materials.
10:00am – 12:00pm Lab: Students will make polymer based slime (Glue vs PVA, glowing, magnetic, testing properties) (Room PF 314)
12:00am – 12:30pm Lunch (Students bring lunch) (30 mins, Room IDC 116)
12:30pm – 1:30pm Lab: Shape Memory (Room IDC 116)
1:30pm – 2:00pm Talk from Dr. Wilner about drug delivery science.
2:00pm – 3:00pm 3D Printing Demo at U-imagine center (Owen Tolton)
3pm – 5pm (Aftercare, Check Out in Room IDC 116)

<u>Optics & Electromagnetism Day (Friday, June 28th):</u>

<u>*This day will last until 5pm*</u>

Taught by Jason/Max
Topics covered: Optics, electricity and magnetism
<u>Day Schedule</u>:
9am - 9:30am Drop Off, Check-In (Room IDC 116)
9:30am - 10am (Slides) What kinds of materials have magnet/electric properties?
10am – 12:00pm EM demo, magnets in tubes, Van de Graaff Generator, lasers and diffraction, spectroscopy materials (Room IDC 116)
12:00pm – 1:00pm Lunch provided (60 mins, Wismer)
1:30pm – 2:30pm (Slides) Lab: Piezoelectric Materials (Room IDC 116)
2:30 – 3:00 pm The future of materials science: discussion on nanomaterials, quantum dots, drug delivery, biomaterials and solar cells. (Room IDC 116)
3:00 – 3:30 pm Certificates, end of camp survey and photo
3:30 – 5:00 pm N_2 ice cream! (Outside PF)
5pm – (Check Out in Room IDC 116)

III. Activity Handouts

In the following section we have all handouts for each laboratory activity. These handouts were passed out to students to read before each activity. Students were also required to answer certain questions in their lab notebooks as they were doing the lab.

Lab 1: How Strong is Your Chocolate?

Objective: To demonstrate how material properties, such as microstructure, can influence the strength of a material.

Keywords:

· **mechanical properties** – the description of how a material behaves in response to applied forces.

· **stress** – the force applied per unit area.

· **3-point bending test** – a standard test used to measure the flexural strength of a material.

· **microstructure** – the structure of a material as observed through microscopic examination.

Materials List:

· plastic cups with twine

· 1 mass balance

· pennies – each group will need approximately 350 pennies.

· aluminum foil to catch the chocolate when it falls

· rulers

Lab Description: In this lab, different types of chocolate bars will be tested to demonstrate the influence of different microstructures on the flexural strength (i.e., stress) of the chocolate bar. The strength of the chocolate bars will be measured using a conventional 3-point bending test set-up as shown in Figure 1.

For this test set-up, chocolate bars are placed on two supports (making two points of contact), and a force is applied to the center of the bar (making the 3rd point of contact in the 3-point bending test). The **flexural strength** of the bar is essentially the highest stress that the material experiences during its moment of rupture (failure) and can be calculated from **Eqn. 1**:

$$\sigma = (1.5 * P * L) / (w * t^2)$$

where σ is the flexural strength (MPa), P is the applied force (N), L is the span length (mm), **w** is the width of the bar (mm), and t is the thickness of the bar (mm).

Instructions:

1. Measure and record on your data sheet the following information about the bar:
    a. Type (milk chocolate, dark chocolate, crisped rice, cookies and cream)

b. Width of the bar (mm), ***w***

c. Thickness of the bar (mm), ***t***

For each type of chocolate bar, make a prediction of how many pennies you think the chocolate bar can hold. Which one do you think will hold the most pennies before it breaks? Why?

2. Position two desks so that the chocolate bar can span across the space between the desks. Approximately ½ inch of the chocolate bar should be touching each desk.

3. Measure and record (in mm) on your data sheet the length of the chocolate bar that is not supported by the desks. This is called the length of the support span, ***L***.

4. Place the twine with the cup attached across the middle of the chocolate bar so that the cup hangs freely below the chocolate bar as shown in Figure 2.

5. Place the protective mat on the floor to catch the chocolate when it falls.

6. Create a paper funnel by rolling a piece of paper and either stapling or taping it.

7. Using the funnel, start placing the pennies into the cup, one at a time. The pennies should be funneled in at a steady pace, ensuring that each penny lands in the cup before the next penny enters the cup (a pace of two to three pennies per second is good). Try funneling the pennies in a way that they do not fall a large distance when they enter the cup.

8. Continue placing pennies into the cup at a steady rate until the chocolate bar fractures (breaks). Be sure to note any deflections or bending of the chocolate bar during the loading process. Once it breaks, look at the fracture surface and record any observations.

9. Find the mass (in grams) of the cup, string, and the pennies in the cup at fracture using a mass balance. The force, ***P***, applied to the chocolate bar can then be calculated as follows:

***P* = (weight of cup, twine, and pennies)*(acceleration due to gravity = 9.81m/s^2)**

10. Use the force, ***P***, found in step 12, to calculate the flexural strength of the chocolate bar using **Eqn. 1**.

11. Repeat steps 1 - 12 for each chocolate bar to be tested. **Once you tested each bar write the Force and Flexural strength for that bar on the board.**

Data Sheet for a Chocolate Bar

Type of bar	Width (w)	Thickness (*t*)	Length of Support Span (*L*)
Weight of the cup/twine/pennies when the bar failed (grams):			

Weight of the cup/twine/pennies when the bar failed (grams):

Calculation of load, P:
<u>Calculation of the bar's flexural strength, σ:</u>

1. Did you notice any changes in the chocolate bars during the loading process? Were these changes the same for all of the chocolate bars or different?

2. Which type of chocolate had the highest flexural strength? The lowest flexural strength?

3. Which type of chocolate broke under the greatest force? The lowest force?

4. Why do you think the bars had different strength values?

<u>Now look at the data we collected as a class on the board</u>

5. Which bar had the highest standard deviation (values that were different from each other) for its flexural strength? Why do you think this is so?

6. Which bar had the lowest standard deviation (values that were different from each other) for its flexural strength? Why do you think this is so?

Clean Up: Eat the chocolate! Clean any chocolate residue from the cup and twine with a wet paper towel and return the cup and twine to your teacher.

Lab 2: Engineered Concrete

Objective: To demonstrate how preparation (design) of a material can affect the final material properties and to provide an introduction to composites.

Introduction:
Composite materials, such as concrete, exhibit characteristics different from the characteristics of the individual materials used to create the composite. In concrete, the addition of sand, rock, or fibers provides reinforcement, and the cement paste provides a way of bonding the materials together.

Keywords:
· Portland cement – a fine powder composed primarily of ground clinker (mostly ground limestone).
· concrete – a composite material composed of Portland cement, water, and aggregate.
· composite – a material that is composed of two or more materials and has different properties than the original materials.
· design – a plan for how to prepare a material or a method for combining the materials in a composite:
- **◊ percentage of each material that should be added**
- **◊ how to combine the materials**
- **◊ curing conditions, etc.**

· reinforcement – a material that is typically added to another material to give it increased mechanical properties.

Materials List:
· plastic measuring spoons
· one balance
· Portland cement (200g per student for each part of the lab)
· plastic cups
· styrofoam bowls (six for each part of the lab)
· popsicle sticks
· ruler
· plastic wrap
· reinforcement items (*sand, rice, bobby pins, rocks*)

Safety Precautions: The Portland cement will be a very fine powder. Care should be taken when transferring the powder from the bag to the plastic cups to keep from generating a dust cloud. If a cloud occurs, allow the powder to settle and then wipe it up with a damp

paper towel. Short-term skin exposure to Portland cement is not harmful, but you should avoid skin contact if possible. If you get some of the wet or dry cement mixture on your hands, wipe your hands off with a damp paper towel immediately, before the cement has time to dry. If needed, ask your teacher for gloves to help protect you from skin exposure to the cement. (Gloves)

Instructions:

<u>Day #1</u>

1. Place 200g of cement powder into a Styrofoam bowl, if it has not already been done.

2. Fill another plastic cup with water for your group to share.

3. Use between 15 – 20 spoonfuls of water to mix the cement. Keep track of which bowl got which amount of spoonfuls. Make two cement pucks this way. Put the spoons of water into the pre-measured cement. Do not "dump" a large amount of cement powder into the cup as this usually creates a small dust cloud. Stir the mixture with a popsicle stick or plastic spoon until well blended. Do not add any reinforcement items! These two pucks should be water + cement only.

4. Calculate the water to cement (w/c) ratios using the equation below:

Write this value on each of your bowls.

5. Think about what you want to test as your reinforcement items. Think about which w/c ratio you will use.

Why did your group choose these?

6. Once you have chosen which reinforcement items you will use and which w/c ratio you will use you are ready to make your composite pucks. Each student will make his or her own puck. Use the spoonfuls of waters which correspond to the w/c ratio you choose and no more than 50g of any reinforcement item (you can choose two items but they can't exceed 50g together). Label each bowl with your name, the w/c ratio, and the reinforcement items used. Also make note of this in your lab notebook.

7. Cover the top of the bowl/ pipe mold with plastic wrap and allow it to cure overnight. Make note of any observations.

Lab 3: Mineral Identification Lab

Mineral Resources in Our Lives

The properties and chemistry of minerals are highly significant in our everyday lives. Your task, with your partner(s), is to figure out which mineral is in the various products placed around the room. *Consider the physical properties of the mineral as well as it's chemical formula!*

Mineral #	**Mineral Name**	**Chemical Formula**
1	Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$
2	Bauxite	$Al(OH)_3$ - $AlO \cdot OH$
3	Calcite	$CaCO_3$
4	Chalcopyrite	$CuFeS_2$
5	Galena	PbS
6	Graphite	C
7	Gypsum	$CaSO_4 \cdot 2H_2O$
8	Halite	$NaCl$
9	Hematite (red)	Fe_2O_3
10	Hematite (specularite)	Fe_2O_3
11	Kaolinite	$Al_2Si_2O_5(OH)_4$
12	Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$
13	Quartz	SiO_2
14	Talc	$Mg_3Si_4O_{10}(OH)_2$

Which mineral is in each product? (*Choose 1 different mineral per product*)

Products	**Associated Mineral #**	**Associated Mineral Name & Reason**
Toothpaste, Cheerios, & Antacid		
Glass & Sandpaper		
Table Salt & Road Salt		
Jewelry		
Baby Powder & Makeup		
Pencils		
Drywall & Plaster	7	Gypsum
Sparkly Eye Shadow	12	Muscovite
Blush		
Car Battery		
Porcelain	11	Kaolinite
Copper Wire, Pennies, & Matches		
Aluminum Foil		
Fertilizer		

Mineral Search in Building

How many of these minerals can you find in the building? Write down from what region they are from on the card provided. Do they look different from the materials you identified in lab?

Mineral Name	Where are they from?	What do they look like?
Apatite		
Bauxite		
Calcite		
Chalcopyrite		
Galena		
Graphite		
Gypsum		
Halite		
Hematite (red)		
Hematite (specularite)		
Kaolinite		
Muscovite		
Quartz		
Talc		

Composite Material Search (Campus)

A composite building material:

Describe the material	What do you think it is made out of

A composite material in a piece of art:

Describe the material	What do you think it is made out of

A composite material for sports (track, bleachers, etc.):

Describe the material	What do you think it is made out of

Lab 4: Thermal Shock

Objective: To illustrate thermal shock and the effects of differing amounts of modifier on the properties of glass.

Keywords:
· **sodium flare** – a bright yellow flame caused by the reaction of an oxygen-rich flame with glass containing sodium.
· **coefficient of thermal expansion** – the amount of expansion (or contraction) per unit length of a material resulting from one degree change in temperature.
· **thermal conductivity** – the property of a material that describes its ability to conduct heat.
· **thermal shock** – the way in which some materials are prone to damage if they are exposed to a sudden change in temperature.

Materials List:
· soda-lime (flint) glass rods
· borosilicate glass rods
· fused silica (quartz) glass rods
· glass beaker
· Bunsen burner
· strike lighter
· ice water

Safety Precautions: It is possible for small pieces of glass to become airborne during the quenching of the rod in ice water, so wear goggles and conduct experiment inside the fume hood.

Background:
Thermal shock (indicated by glass breaking) depends mostly on thermal conductivity and coefficient of thermal expansion. **Thermal conductivity** refers to how well heat is conducted. The better the conductivity, the more rapidly and evenly heat is distributed. The better the conductivity, the less chance there is of thermal shock (inversely proportional). All three types of glass rods in the demonstration have about the same thermal conductivity. The **coefficient of thermal expansion** refers to the amount of expansion per unit of length per °C. It is easy to measure and varies greatly in glass. The lower the coefficient, the less stress caused by a sudden temperature change. The lower the coefficient, the less chance of thermal shock (directly proportional).
Based off of this information, what do you think will happen if you heat and rapidly cool each of the materials given? Why?

Instructions:

1. Prepare a glass beaker with ice water.
2. Have a teaching assistant turn on the Bunsen burner.
3. Using a plier heat one end (about an inch) of the **soda-lime glass** in the flame. Try to hold the glass rod so that the same length of glass is in the flame throughout the heating. Watch for the "sodium flare" that occurs as the glass heats up. What do you notice as you heat the rod? Does the rod sag or slump?
4. Remove the rod from the flame and place directly in the ice water. What happens to the rod once you placed it in water?
5. Using a plier heat one end (about an inch) of the **borosilicate glass** rod in the flame. Try to hold the glass rod so that the same length of glass is in the flame throughout the heating. Watch for the "sodium flare" that occurs as the glass heats up. What do you notice as you heat the rod? Does the rod sag or slump? Is there more or less flare than with the soda-lime glass?
6. Remove the rod from the flame and place directly in the ice water. What happens to the rod once you placed it in water?
7. Using a plier heat one end (about an inch) of the fused silica glass rod in the flame. Try to hold the glass rod so that the same length of glass is in the flame throughout the heating. Watch for the "sodium flare" that occurs as the glass heats up. What do you notice as you heat the rod? Does the rod sag or slump? Is there more or less flare than with the glasses you tried before?

Of the three types of glass used in the demonstration (soda-lime, borosilicate, and fused silica), which would be the best for the following uses:
solar panels, everyday drinking glasses, cookware, bathroom mirrors, high temperature furnace, windows

Cleanup/Replacement Parts: Make sure Bunsen burner is turned off and allow it, the beaker, and the water to cool down. Pour out the water. Using a paper towel, carefully wipe the broken glass pieces into a trash can or broken glass container. Place unused portions of the rods into a bag.

Additional Experiment: Index of refraction

Index of refraction: measure of the bending of a ray of light when passing from one medium into another.

Index of refraction for materials:
Vegetable oil: 1.47
Soda-lime: 1.52
Borosilicate: 1.47
Fused silica: 1.45

Instructions:

1. Fill a glass beaker with vegetable oil.
2. One at a time, place each rod into the oil. What do you notice? Does one appear to disappear? Which one?

What do you think is going on?

Lab 5: Candy Fiber Pull

Keywords:

· **amorphous** – non-crystalline materials that lack a long-range atomic order.
· **glass –** an amorphous, brittle solid which exhibits a glass-liquid transition when heated.
· **liquid** –matter having a definite volume, but no shape.
· **solid** – matter characterized by structural rigidity.
· **viscosity** – an internal property of a fluid that offers resistance to flow.
· **fiberglass** – a material fabricated from extremely fine fibers of glass and is used in a variety of applications ranging from household insulation to a reinforcing agent in ladders and automotive body panels.

Safety Precautions: The hot plate and the beaker will get very hot. Ask a lab instructor before moving the beaker. Allow the beaker and hot plate to cool before cleaning.

Instructions:

1. Place four Jolly Ranchers® into the beaker.
2. Set the hotplate to 200ºC.
3. Stir the Jolly Ranchers® while heating for approximately 10 to 15 minutes. The Jolly Ranchers® should begin to melt.

Note: The Jolly Ranchers® can burn! Pay close attention while melting the Jolly Ranchers® and be sure to stir them throughout the heating process. If they start to burn, reduce the heat (or remove the beaker from the heat) and continue to stir.

Make a prediction: What do you think will happen when you pull some of the molten Jolly Ranchers out of the beaker?

4. Once the Jolly Ranchers® are in liquid form, use the wooden skewer/popsicle stick to pull one fiber from the beaker by dipping the skewer into the molten Jolly Ranchers® and removing it slowly.
5. Take turns pulling fibers.

How does the Jolly Ranchers fiber differ (in terms of texture, flexibility, shape, etc.) from the original solid Jolly Rancher?

Compare the texture and flexibility of the fiber to the solid Jolly Rancher. Are there any changes in the properties of the fibers as a function of length (i.e., do shorter fibers feel or look different than longer fibers)?

What happens when you eat the Jolly Ranchers fibers?

6. **Fiber Competition!** Lab instructors will take students outside to have a fiber pulling contest.

How long do you think you can pull a fiber?

(After the competition) How long was your longest fiber? Why did it finally break?

Lab 6: Glass Bead on a Wire

Objective: To demonstrate that glass can be a "phase of matter" rather than a particular material and to examine the unique ability of glasses to absorb other ions during thermal treatments.

Background Information: Glasses are amorphous solids, meaning that they have no long-range order of their atoms. Crystalline materials have an orderly arrangement of atoms within their structure (Figure 1). Several materials that can be used to create a glass begin as a crystalline or semi-crystalline material, like borax crystals ($Na_2B_4O_7 \cdot 10H_2O$) or sodium borate decahydrate. Removing water causes the crystalline structure of borax to lose its orderly arrangement of atoms, leaving a transparent, glassy solid behind.

Keywords:

· **amorphous** – non-crystalline solid that lacks a long-range order of atoms.
· **oxidation** – the addition of oxygen to a material.
· **reduction** – the removal of oxygen from a material.
· **borax bead test** – a heat-induced transition of borax from a crystalline state to an amorphous state which is typically used to test for the presence of certain metals.
· **water of crystallization** – water that is found in the crystalline structure of a material

Safety Precautions: Safety glasses should be worn during this lab. The wires will get very hot when placed in the Bunsen burner flame. Use pliers to hold the wires while heating. Borax is toxic to humans if ingested in large quantities, so students should avoid skin contact with the powder to reduce the risk of accidental ingestion. The glass beads can fall off the wire, so caution students not to "flick" the wire when they have a hot bead.

Materials List:

· 20 feet copper wire (18-gauge)
· 20 feet nichrome wire (20-gauge)
· powdered borax (available for purchase as a laundry booster from stores such as Walmart®)
· Bunsen burners (should have one burner for every student, but students can share if needed)
· needle nose pliers
· watch glass

<u>Instructions:</u>

1. Cut two pieces of copper wire and two pieces of **nichrome wire**, each about 12 cm long.
2. Place a small amount of borax (about a teaspoon) in a watch glass.
3. Use the pliers to form a small loop on the end of each wire. The loop should be slightly larger than the eraser on the end of a pencil (Figure 5).

4. Using a Bunsen burner, heat the loop at the end of one of the copper wires until it gets red hot. Be sure to use the pliers to hold the wire while heating.
5. Dip the hot end of the wire into the borax.
6. Carefully heat the borax on the wire until it is melted and the loop fills in by placing the loop in the purple-colored outer flame (also called the oxidizing region of the flame). When the bead has a transparent color with very few air bubbles, you may add more borax if you would like to make a larger bead. This process can be repeated to form a spherical bead if desired, but it is also ok to make a flat bead (this typically only takes one borax treatment). This bead should have a sky blue color.
7. Repeat steps 4 - 6 with the other **copper wire**, but during step 6, hold the borax-covered wire loop in the blue inner flame (also called the reducing region of the flame). Keep it red hot for 10 to 15 seconds, then cool it for 10 seconds by lowering it into the darker blue flame just above the Bunsen. The color of this bead should be red. NOTE: Be sure to let the bead cool for a few moments before inspecting the color. The color produced is temperature dependent.
8. Repeat steps 4 - 6 with one of the **nichrome wires**. The bead produced should be a shade of green. Nichrome wire is typically composed of nickel, chromium, and sometimes a small amount of iron. Nickel produces a bead that is red to violet in color when heated in the oxidizing portion of the flame. Chromium produces a yellowish-green bead, and iron a yellowish-orange bead. Depending on how much of each element is present in the wire, the color of the bead will vary.
9. Repeat steps 4, 5, and 7 with the other **nichrome wire**. The bead produced should be a shade of green as well. Nickel turns grey when heated using the reducing flame. Chromium turns green, and iron turns green as well. Depending on how much of each element is present in the wire, the shade of green will vary.
10. Once you are satisfied with the size and color of the bead, allow the bead/wire to cool completely before placing the bead/wire in a plastic bag to take home.
11. You can try to remove the beads from the wire by reheating the bead and then plunging the loop into cold water. This works best with spherical beads.

Write down the colors of the beads your group achieved. Were they as predicted? If not, then what do you think happened? What were some challenges of the lab? What did you do to overcome them?
Can crystalline materials become amorphous? How?
How can you get two different colored beads from one wire?

Cleanup: Turn off the Bunsen burners and allow them to cool completely before putting them away. Allow all the wires and beads to completely cool. Students should place the beads/wire in a plastic baggie to take home. Place any unused wire back in the kit.

Lab 7: Polymer Slime

Objective: To learn about chemical reactions that form crosslinked polymers through making slime.

Background:

Simple Slime: The glue has an ingredient called polyvinyl acetate, which is a liquid polymer. The borax links the polyvinyl acetate molecules to each other, creating one large, flexible polymer. This kind of slime will get stiffer and more like putty the more you play with it.

Super Slime: Polyvinyl alcohol (PVA) is a liquid polymer and is therefore formed from long chains of connected molecules. The sodium tetraborate forms hydrogen bonds with oxygen present in the PVA chains. Hydrogen bonds occur when the positive charge of the hydrogen atoms attracts the negative charge of the oxygen atoms within the compound. The hydrogen bonds link the individual PVA strands to each other, creating a "blob" of slime. Since hydrogen bonds are weak, they will break and reform as you hold the slime or let it ooze onto a flat surface.

Oobleck: The flow and movement of a fluid is affected by its viscosity, or how sticky and thick it is. Quicksand and the cornstarch-water mixture are both non-Newtonian fluids. Non-Newtonian viscosity changes with the type of force applied to it. The viscosity of Newtonian fluids (such as water and honey, which follow Sir Isaac Newton's law of viscosity) is dependent only on the temperature and pressure of the fluid, not the force applied to it. For instance, warm honey (less viscous) flows much more freely than cold honey (more viscous).

Keywords:

· **polymer** – a substance that has a molecular structure consisting chiefly or entirely of a large number of similar units bonded together.

· **phase change** – a change from one phase to another (often caused by a change in temperature).

· **thermal shape memory** – the ability of a material to return to its original, cold-forged shape when heated.

· **alloy** – a metal containing two or more elements.

· **nanoscale** – features smaller than 1/10 of a micrometer (400 times smaller than the width of your hair).

· **macroscale** – features measurable and observable with the eye.

Materials List:

· Gloves
· Plastic cups
· Stirrers

- Simple Slime
    - 1/8 cup of PVA school glue
    - ¾ tsp of slime activator (borax water solution)
- Super Slime
    - 50 mL of 4% PVA (polyvinyl alcohol)
    - 5 mL of slime activator
- Oobleck
    - 2 Tbs. cornstarch
    - 1 Tbs. + (2 + ¼) Tsp. water

Safety Precautions: Just don't eat the slime please.

Instructions:

Simple Slime

1. In one red cup mix 1/8 cup of glue and any liquid coloring or powder now. Observe the consistency of the solution now.
2. Add ½ or ¾ tsp. of slime activator to the glue and stir slowly.
3. The slime will begin to form immediately. Lift some of the solution with the stir stick and observe how the consistency has changed from Step 1.
4. Stir as much as you can. Once there is no liquid in the cup, pull out the slime and knead it with your hands until it gets less sticky and the two compounds bond completely.
5. When it seems well formed, you may take your gloves off.

Super Slime

1. In one red cup mix 10 tsp. of 4% PVA (if you want any liquid coloring add 4 drops now)
2. Add 1 tsp. of slime activator to the PVA and stir slowly.
3. The slime will form as a gel.
4. Stir as much as you can. Once there is little to no liquid in the cup, pull out the slime and knead it with your hands until it gets less sticky and the two compounds bond completely. Compare the viscosity and characteristics of this slime to the first.

Place both the simple slime and the super slime on your table, which one oozes outward more? Why?

Oobleck

1. In a plastic bag, combine 2 Tbs. of cornstarch and 1 Tbs. + (2 + ¼) Tsp. of water together to form a mixture that looks like heavy whipping cream and has the consistency of honey.

1. Each member of the group will pour their cornstarch mixture into the aluminum pan on the table. Continue steps 1 and 2 until there is enough to cover the bottom of the pan.
2. After making enough of your mixture, gently lay your hand on the surface of the cornstarch-water mixture. You should notice that your hand sinks in the mixture like you would expect it to do. Move your hand through the mixture, slowly first and then trying to move it really fast. Was it easier to move your hand slowly or quickly through it?
    1. Make your mixture deep enough to submerge your entire hand in it. Try grabbing a handful of the mixture and pulling your hand out quickly. Then try again, this time relaxing your hand and pulling it out slowly. Did you notice a difference?
    2. Try hitting the cornstarch-water mixture. (Be careful not to hurt yourself) Make sure to hit the substance hard and pull your hand back quickly. Did the substance splatter everywhere or did it remain in the bowl? Why?

Cleanup: Wash your hands and remove the table cloths/wrap from the tables and throw it away. Throw away all used items. If you would like to keep your slime put it into a plastic bag and keep in the refrigerator at home.

Lab 8: Shape Memory Alloys

Objective: To learn how the motion of atoms under added heat can change the shape of metals.

Keywords:

· **phase** – the region of a material that is chemically uniform, physically distinct, and usually mechanically separable.

· **phase change** – a change from one phase to another (often caused by a change in temperature).

· **thermal shape memory** – the ability of a material to return to its original, cold-forged shape when heated.

· **alloy** – a metal containing two or more elements.

· **nanoscale** – features smaller than 1/10 of a micrometer (400 times smaller than the width of your hair

· **macroscale** – features measurable and observable with the eye.

Materials List:

· 6 inches of nitinol wire
· 6 inches of steel wire
· glass beaker
· hotplate
· needle nose pliers
· water

Safety Precautions: Safety glasses should be worn in case of water splashing. The beaker and hot plate can get very hot. Use the beaker tongs to handle the beaker during the demo to avoid accidental burns. After the demo, be careful not to touch the wire, water, beaker or hot plate until they have completely cooled!

Instructions:

1. Fill the beaker with water.
1. Place the beaker on the hot plate and turn to the high temperature setting. The water should be heated to just below boiling.
2. Gather a nitinol wire and a steel wire. How do the wires differ (color, texture, flexibility, etc.) from each other?
3. Bend the nitinol wire to a desired shape. Do not make sharp corners in the nitinol wire or tie it into knots. The wire is limited on how much deformation it can recover from.
4. Place the nitinol wire in the hot water. What happens when you drop the nitinol wire into the water?

5. Carefully remove the nitinol wire from the beaker using the pliers.
6. Repeat steps 4 - 6, trying different shapes and amounts of deformation. (Try coiling the wire into a tight spring and tossing it into the water.)
7. Repeat steps 4 - 6 with the steel wire. What happens when you drop the steel wire into the water?

Extra: Try coiling the wire into a tight spring and tossing it into the water. What happens?

Cleanup: Turn off the hot plate and allow it, the beaker, and the water to cool down. Pour out the water.

How did the nitinol and steel wires behave relative to each other? Why do you think this is?

Lab 9: Piezoelectric Materials

Objective: To demonstrate the piezoelectric effect in several materials and explain why this property exists in certain materials.

Keywords:
· **piezoelectric** – the effect of generating electric charge from applied force; "piezo" comes from the Greek for "pressure."
· **ceramic** – classification of materials which are inorganic, non-metal solids.
· **structure** – the arrangement of atoms within a material.
· **potential** – difference in electric charges resulting in the capacity to do work.
· **force** – influence exerted on an object, such as pressure or tension.
· **transducer** – a device that converts small amounts of energy from one kind into another.

Materials List:
· piezoelectric ceramic disks
· LEDs
· alligator clip sets
· voltmeter

Safety Precautions: Too much force on either piezoelectric material can permanently damage them.

Instructions:
1. Connect 1 LED to a piezoelectric ceramic disc so that the long wire of the LED is connected to the red wire coming from the disk and the other wire of the LED is connected to the black wire of the disk.
2. With a very light tap, slowly increase the force until the LED visibly flashes with each tap. It is important to simply tap the disk and to not apply steady pressure. What do you see?
3. Now use a voltmeter in place of the LED to measure the voltage generated by the piezoelectric. Mark in your notebook at least 5 voltages you see.
4. Try connecting two piezoelectric materials in series and try to generate more voltage by simultaneously activating both materials. Were you able to achieve a higher voltage? If so what was your peak voltage?

Lab 10: E&M Demonstrations

Objective: To demonstrate electricity and magnetism in terms of electron movement. Show how magnetic fields are produced by electrons moving through a wire and in solenoid coils. Describe the differences between electromagnets and temporary/permanent magnets.

Materials List:
· Solenoid coil and insertable rod apparatus
· Aluminum and copper ring
· Van De Graaff generator

Safety Precautions: When asking the students to put the copper and aluminum rings over the rod protruding from the solenoid coil the induced current in the rings will cause them to heat up. Caution students to let go if it gets to hot.

Instructions:

1. Turn on the solenoid coil and attempt to place each ring on the rod.
2. Turn off the solenoid and place a ring on the rod on top of the coil.
3. Back up and turn the solenoid coil on (try and catch the ring).
4. Turn on Van De Graaff generator.
5. One student will keep a hand on the Van De Graaff generator and charge up for 4 minutes.
6. A set of 5 students should hold hands behind the student charging with the generator.
7. After 4 minutes have the chain of students make contact with whomever is charging on the Van De Graaff.

Spectroscopy

Objective: To demonstrate the way light diffracts to create a spectrum, it displays how we can excite ions to create light energy and how scientists can differentiate excited noble gases by exciting them.

Materials List:
· Handheld spectroscopes
· Gas ionization tubes
· Diffraction gradient squares (optional)
· Print-outs of emission spectrums

Safety Precautions: Do not touch the fluorescent tubes. They use a lot of power and can shock you, let the teachers switch out the tubes as needed.

Instructions:

1. Grab a handheld spectroscope or diffraction gradient square.
2. Look through the spectroscope directly at the light, if using a square look off to the side to see the emission lines.
3. Once the emission lines are clear compare them to the spectrums on the print-out to identify the excited gas.

Figure 1. Group photo of student GaMES campers and instructors at Ursinus College.

IV. Analysis Discussion

In order to measure interest and understanding for the students participating in the week long camp, we gave out a survey at the beginning and end of the camp. The survey had questions to gauge whether the students had any interest in sciences as well as whether they were considering a career in science or materials science specifically. The students marked a number between 1, does not apply to me, and 10, this describes me, for each question. The survey also included a list of vocab words where they would indicate which words they knew. This allowed us to see what vocabulary they became comfortable with or understood by the end of the camp.

Looking at the data collected we could conclude that most of the students marked they had an interest in science to begin with. Comin into the camp, the students had an average of 7.4 for "I am very interested in science" and by the end of the camp there was still an average growth of 0.6. For "I would like to have a career in science" there was an average growth of 1.27, and a difference of -0.58 for "I would rather be at home".

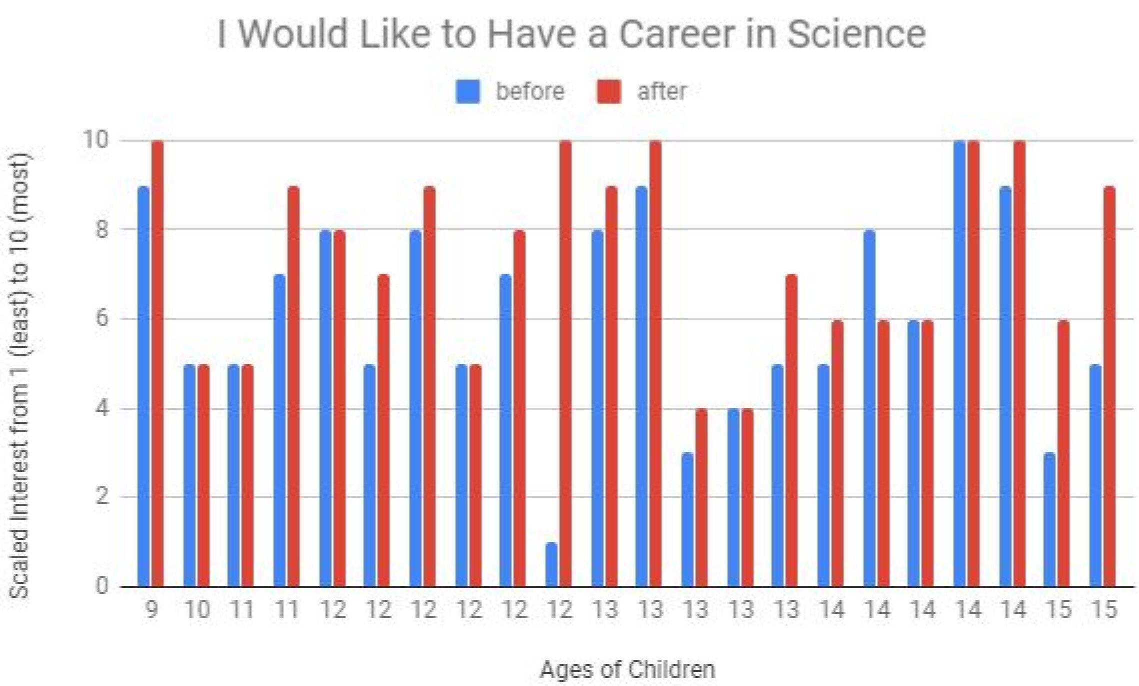

Figure 2. Graph of GaMES campers responses from the beginning and end of the camp on their future aspirations.

Surveys also showed that by the end of the camp they had a lot more confidence regarding materials science. The survey had a statement gauging how well they understood materials science "Knowledge of materials science", to which the student response average was 1.1 coming in. The same students marked an average of 8.6 at the end of the survey. This marked growth in confidence good in the context of the perceived expectations that come with aspiring to be part of any STEM career field. The prerequisites that many assume are needed to have those aspirations scare many younger students away. Finding a way to dissipate that fear is very important and going from an average of 1.1 to 8.6 in this part of the survey is worth noting as a success.

In order to measure understanding there was a section on the survey where the kids marked which words they knew before and after the survey. The average number of circled words coming into the camp was 20.8 and grew to 33.1 by the time they took the exit survey.
This data was taken from the 26 students who participated in the week long GAMES camp supports the idea that the inquiry-based approach and modeling techniques did help raise interest in science for the attending students. There is also evidence for growth in understanding of materials science based on the key words they were confident with.

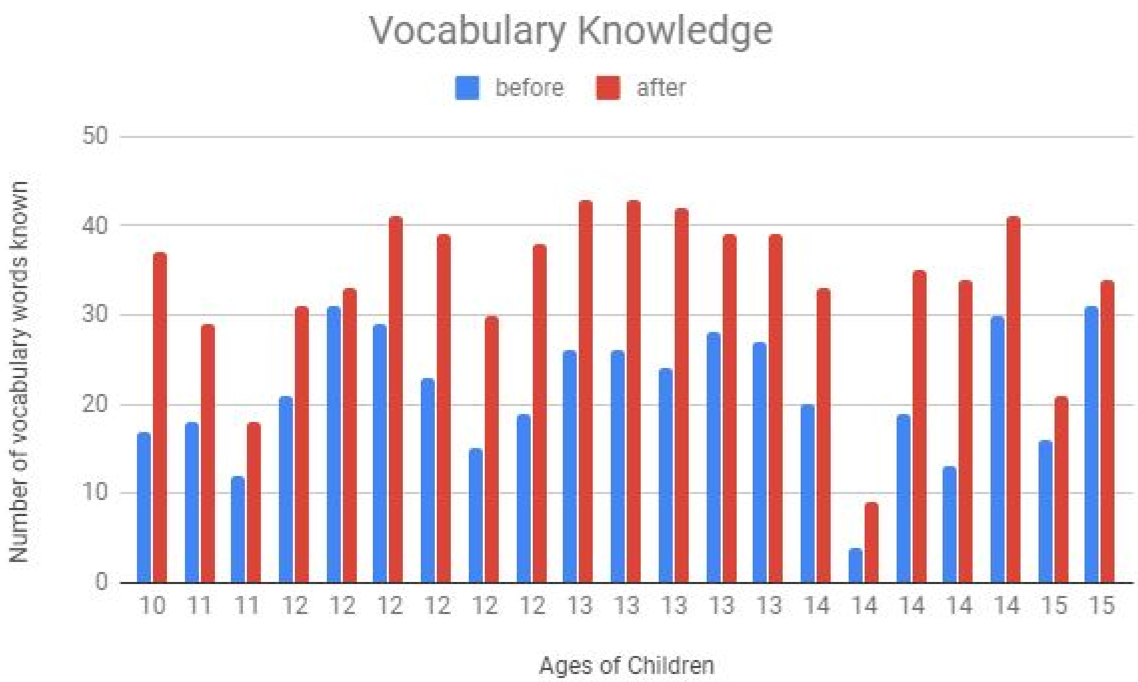

Figure 3. Graph of student GaMES campers reponses before and after the camp on how many college level science words they would be comfortable using. (One student omitted due to saying they knew more words when they came in than when they left.)

V. Conclusion & Future Plans

This was the first attempt at a camp and as such was a learning experience for everyone involved. This program not only successfully introduced these students to topics seen in college level courses like: coefficient of thermal expansion, microstructure, polymer cross-linking, etc.; but it also provided valuable insight into what curriculum would be more proactive for different age groups. The camp showed that it was possible to demonstrate qualitatively why certain materials have their specific mechanical properties and how applicable that information is in regard to tools, structures, and composite materials within our contemporary world. In addition, we gained experience teaching the age group 9-15 which leads us to believe you should structure classes differently for the younger on the spectrum than for the older.

The most difficult thing about this program was the age range of 9 to 15 that participated. The younger students were much easier to manage but lacked the attention span necessary for in depth lectures. An ideal environment for the younger students would be quick talks and lab after lab. As long as the kids age 9-11 have something to do and engage with then they have a proactive learning experience. With age groups 12-15 it proved useful to give strict warnings about disruption while others were talking, but it is reasonable to expect that age group will be the most difficult to lead from one lab to another. The older students, 14-15, seemed restrained in class and susceptible to more content in the actual pre-lab lectures. The older age groups would have likely also benefited from being asked to do more (in terms of complexity of the question) on the handouts for the labs because they did finish more quickly.

VI. References

1. The American Ceramics Society Materials Science Kits (1995)
2. J. Kremer, “Why Physics First?”
http://discussionphysics.blogspot.com/p/physics-first-resources.html
3. A. Hobson, “Considering Physics First,” Phys. Teach. 43, 485 (Nov. 2005).
4. G. Popkin, "Physics First Battles for Acceptance," APS News. Vol. 18, No. 7, p3 (July 2009).

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