Nanoparticle Stained Glass

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General Description

Cart demo

This activity highlights the connection between nanotechnology and art—specifically though the production of medieval stained glass. Visitors will observe that nanoparticles behave differently than bulk material. Visitors will create (in collaboration with other visitors) a stained glass panel using solutions of nano-sized gold and silver particles. Visitors will be given the opportunity take a piece of mock stained glass home with them.

Program Objectives

Big idea: Interesting properties of gold and silver nanoparticles have been used for centuries by stained glass artisans.

Learning objectives:

By participating in this activity, visitors will:

1. Understand that nanoparticles of gold and silver behave differently than bulk gold and silver.
2. Appreciate the interconnection between science and art.
3. Learn that nanotechnology has been used since the Middle Ages, even though stained glass artisans did not know they were using this technology.

NISE Network Main Messages:

[x] 1. Nanoscale effects occur in many places. Some are natural, everyday occurrences; others are the result of cutting-edge research.
[x] 2. Many materials exhibit startling properties at the nanoscale.
[ ] 3. Nanotechnology means working at small size scales, manipulating materials to exhibit new properties.
[ ] 4. Nanoscale research is a people story.
[ ] 5. No one knows what nanoscale research may discover, or how it may be applied.
[ ] 6. How will nano affect you?

Nanoparticle Stained Glass

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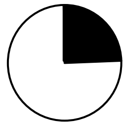
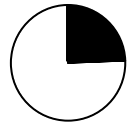
Time Required

Set-up	Program	Clean Up
		
6-8 hours (total prep)	15-20 minutes	15 minutes

Background Information

Definition of terms

Nano is the scientific term meaning one-billionth (1/1,000,000,000). It comes from a Greek word meaning “dwarf.”

A *nanometer* is one one-billionth of a meter. One inch equals 25.4 million nanometers. A sheet of paper is about 100,000 nanometers thick. A human hair measures roughly 50,000 to 100,000 nanometers across. Your fingernails grow one nanometer every second.

(Other units can also be divided by one billion. A single blink of an eye is about one-billionth of a year. An eye blink is to a year what a nanometer is to a meter stick.)

Nanoscale refers to measurements of 1 – 100 nanometers (nm). A virus is about 70 nm long. A cell membrane is about 9 nm thick. Ten hydrogen atoms lined up in a row would be about 1 nm long.

At the nanoscale, many common materials exhibit unusual properties, such as remarkably lower resistance to electricity, or faster chemical reactions.

Nanotechnology is the manipulation of material at the nanoscale to take advantage of these properties. This often means working with individual molecules. *Nanoscience, nanoengineering* and other such terms refer to those activities applied to the nanoscale. “Nano,” by itself, is often used as shorthand to refer to any or all of these activities.

Program-specific background

Background on nanoparticles

A material's properties (i.e. electrical behavior, magnetic behavior and color) are sometimes dramatically different on the nanoscale (1-100 nm). For example, a gold ring is yellow and shiny. If heated up, it would melt at 1,946 °F. (Silver melts at 1,762° F.) It conducts electricity. Gold behaves a lot like many of the other metals people are familiar with. If the gold ring were cut in half, each half would have the same properties, e.g., color, melting point, conductivity, etc., as the whole ring. Even if the gold ring were cut many, many more times, perhaps down to the size of a grain of sand, the properties of the small piece of gold would be the same. However, if the small piece of gold were cut in half many more times, until each piece was under 100 nm in size, the properties of the gold would start to change.

One visible property that can change is the color of the nanoparticles. At the nanoscale, gold particles can be orange, purple, green or red depending on the size of the particle. In the solution used in the demonstration, the gold particles are approximately 25 nm in diameter and appear red. Similar changes occur with silver particles on the nanoscale. Silver nanoparticles appear yellow, red or blue, depending on the particle size. The solution used in this demonstration appears yellow because the nanoparticles are approximately 100 nm in diameter.

This property is used in other ways in addition to stained glass. For example, particles of titanium dioxide (TiO_2) have been used for a long time as the sun-blocking agent in sunscreen. The white color of these creams comes from the way that the particles of TiO_2 interact with sunlight. However, nanosized particles of titanium dioxide interact differently with light and appear colorless. Sunscreen manufacturers have used this property to make creams colorless (or clear). In addition to sunscreens, nanoparticles are also used in paint, cosmetics and even inkjet paper.

Interaction of nanoparticles and light

These changes in color occur because these materials interact with light differently on the nanoscale than on the bulk (macro) scale. The color change arises from a phenomenon called *plasmon resonance*.

In a typical bulk metal, some electrons are free to move around and are not tied to a single nucleus. From an electronic viewpoint, the metal looks like a sea of electrons.

When light shines on the surface of a metal, some of the light waves *propagate* (move) along the surface of the metal and give rise to a *plasmon* – a group of electrons moving back and forth in sync across the surface of the metal. The plasmon is said to be in resonance with light when the frequency of the plasmon's oscillation (the rate at which the electrons are moving back and forth) is the same as the frequency of the light that produced it. The oscillating electrons then emit light of their own at the same frequency, producing the color that you see.

In nanoparticles of metals, there are fewer atoms, and thus fewer electrons. Because of this, the electrons are better able to coordinate and move together (as an analogy, 10 students in a classroom can move in a coordinated fashion more easily than 10,000 students in a stadium), and their behavior is governed by quantum mechanics.

Nanoparticles of some metals, such as gold and silver, resonate at frequencies within the visible spectrum of light. The gold nanoparticles in our stained glass resonate at the frequency of reddish-purple light waves, so they emit reddish-purple light themselves. The silver nanoparticles resonate at the same frequency as yellow light, so they emit yellow light.

Different shapes and sizes of nanoparticles give rise to plasmons that oscillate at different frequencies, producing different colors

So what does this have to do with art, specifically stained glass? Medieval artisans unknowingly became nanotechnologists during the glass-making process. Artisans mixed different compounds (like gold chloride and other metal oxides and chlorides) into the molten glass. When they added the gold chloride, it turned the molten glass a rich ruby color. The artisans didn't know it back then, but the color came from nanoparticles of gold, and the different way that nanoparticles interact with light produced a rich ruby color.

Background on stained glass

History of stained glass

<u>Time line</u>
3000 BC – Discovery of glass in Egypt and Sumeria
30 BC-640 AD – Lycurgus cup (Roman Empire)
500 AD-1450 AD – Stained glass windows (Middle Ages or Medieval Period)
1885 AD. – Tiffany & Co. stained glass (Industrial Age)
1974 AD – Norio Taniguchi coins the term "nanotechnology"

The Medieval period in Europe lasted from approx 500 A.D.-1450 A.D. This was when knights and noblemen ruled towns, castles and countryside. Churches played a big role in daily life as Christianity spread organized religion through Europe.

Color in stained glass has historically been related to emotions. The meditative feeling a person gets upon entering a church partially results from the interior lighting. Rich reds and glorious yellows are two colors that were traditionally used in stained glass because of the emotions they invoke. Also, books were rare during this time, and many people were illiterate. In addition to being pieces of art, stained glass windows assumed an educational role by telling stories through pictures. Stained glass windows in cathedrals during the medieval period acted as a visual Bible for the poor.

Often medieval stained glass artisans worked on-site, making and cutting glass sheets and assembling the windows panels in the locations where they were to be installed. Many large French cathedrals (especially in Chartres) often went through two or three generations of stained glass makers before completion.

Making colored glass

The glass itself was made from melted sand (SiO_2). Pure sand required very high temperatures, near 2,500 ºF. However, artisans discovered that adding additional ingredients caused sand to melt at a much lower temperature. A mixture of sand, soda ash, lime, potash and lead oxide caused the sand to melt at temperatures around 1,500 ºF. Once molten, coloring agents, or *colorants*, were added.

The colors in the stained glass can be attributed to different chemical compounds that were added to the molten glass during processing. In some cases, the colorants were part of the basic glass making process (i.e.,impurities found in the sand used to make the glass, or from smoke generated in the firing process).

Artisans noted that different compounds gave rise to different colors. For instance, ruby glass was created by adding gold chloride, while uranium glass, which glows in the dark, was created by adding uranium oxide. Below is a table that lists the different chemical pigments that artisans used to color glass. The sources for chemical colorants (typically metal oxides, sulfides and chlorides) were minerals.

Chemical compound added	**Resulting color**
iron oxides	greens, browns
manganese oxides	deep amber, amethyst
cobalt oxide	deep blue, violet

silver nitrate	yellow
gold chloride	ruby red
selenium oxides	reds
carbon oxides	amber/brown
mix of manganese, cobalt and iron	black
antimony oxides	white
sulfur compounds	yellow, amber, brown
copper compounds	light blue, red, green
tin compounds	white
lead compounds	yellow
nickel oxide	violet
chromic oxide	emerald green
uranium oxide	fluorescent yellow, green
sulfur	yellow, amber
cadmium sulfide	yellow
selenium oxide	red

(pigment chart adapted from: http://chemistry.about.com/cs/inorganic/a/aa032503a.htm and http://geology.com/articles/color-in-glass.shtml (accessed June 14, 2008) Additional information from Armitage, E. Liddall, *Stained Glass History, Technology and Practice*, Leonard Hill Books Limited (London), 1959.)

The artisans didn't know it back then, but the color they observed after adding gold chloride and silver nitrate came from nanoparticles of gold and silver created during the glass process. The different ways that nanoparticles interact with light produced the red and yellow colors the artisans observed. (The other colors observed were generally not due to nanoscale phenomena.)

Stained glass window assembly

In the Medieval Period, artisans designed a pattern for a window panel and determined the size for its particular location. Once the pattern was determined, pieces of colored glass were cut roughly from large sheets to the approximate sizes and shapes using a heated rod or poker. To obtain the exact size and shape, artisans then used use a diamond grinder to grind down the glass to its desired shape. After all the pieces were cut to size, they were pinned onto a soft surface. The pieces of glass were then assembled into a window using lead strips (called lead came) to hold the glass in place. The joints between the glass and the lead strips were soldered together, to fill in the gaps between the glass and the premade lead came. Lastly, the window was glazed to strengthen all of the glass/lead joints.

In the mid to late 1800s, a new method evolved for assembling stained glass windows called the "Tiffany LaFarge Method." This method arose because artists wanted to create designs using glass pieces too intricate and delicate for the lead came method. In the Tiffany LaFarge method, copper foiling is used in place of the lead came. The copper foil could be fitted around the smaller, more delicate pieces, allowing artists to create more intricate designs.

Materials

Presentation:

Power Point slides (available for download)
Meter stick
Consumer products containing silver nanoparticles (e.g., athletic socks or silver enhanced storage containers)

Take-home card:

Take-home cards printed on cardstock (files available for download)
Circular craft punch to make "windows" in cards
Lamination sheets cut in 1.5" x 1.5" squares (2 squares for each take home card)
Pre-made nanostained glass pieces (silver and gold) (see Setup section for preparation)
Scissors
Containers to organize components (suggested)
Colored pencils/crayons (optional)

Collaborative stained glass panel:

Pre-made gold nanoparticles/PVA solution (see below for materials list and Setup section for preparation)
Pre-made silver nanoparticles/PVA solution (see below for materials list and Setup section for preparation)
(Note: Amount of each solution used will vary with size of panel, complexity of pattern, and visitor use. Generally, 50-75 mL of each color will provide more than enough solution for an 18" x 24" Plexi panel)
Plexiglass panel (suggested 18"x24") (available at local hardware stores)
Simulated liquid leading (DecoArt Liquid Leading Paint, available at arts and craft stores or on-line; small bottle approximately $2.00)

2 labeled plastic cups/containers to hold the solutions (best not to use drinking cups, since it makes the solutions look ingestible)
Latex and Nitrile gloves (variety of sizes, available from Fisher Scientific)
Safety glasses (available at local hardware stores or Fisher Scientific)
Paper towels for clean up or spills
White poster board or foam core to go under plexiglass panel to make panel more visible (available at local arts and crafts stores)
Several droppers

Nanoparticle stained glass pieces:
Premade gold nanoparticle/PVA solution (see below for materials list and Setup section for preparation)
Premade silver nanoparticles/PVA solution (see below for materials list and Setup section for preparation)
Silicone baking molds (cupcake/muffin cups work well, available at home good stores, e.g. Target or Bed, Bath and Beyond)
Toaster oven (optional, but recommended, available at home good stores, e.g. Target or Bed, Bath and Beyond)

Note: Each stained glass piece will use approximately 3-5 mL of nanoparticles/PVA solution. Exact volume needed depends on size and thickness of disks made.

Silver nanoparticle/PVA solution: (quantities below will make 250 mL)
Note: The suggested quantities below will make approximately 250 mL of silver nanoparticle/PVA solution. The exact quantity needed to do the hands-on activities will vary, depending on the size of the panel or the number of nanoparticle-stained "glass" disks being created. Adjust the recipe as necessary. Excess solution can be store solutions in tightly sealed bottles for 6+ months without degradation.

Eye protection
Latex or Nitrile gloves
Magnetic stir bar
Hot/stir plate
Ice
Large container to use as ice bath
Paper towels
Graduated cylinders for measuring solution volumes
50ml Erlenmeyer flask or beaker
Droppers/pipettes
0.0189 g $NaBH_4$ (sodium borohydride) (available from Aldrich)
0.017g $AgNO_3$ (silver nitrate) (available from Aldrich)
0.1 g polyvinyl pyrrolidone (PVP) (available from Aldrich)
8-10 g polyvinyl alcohol (PVA) (available from Aldrich)
1 L distilled water

(see Setup section for synthesis procedure)

Gold nanoparticle/PVA solution: (quantities below will make 330 mL)

Note: The suggested quantities below will make approximately 330 mL of gold nanoparticle/PVA solution. The exact quantity needed to do the hands-on activities will vary, depending on the size of the panel or the number of nanoparticle-stained "glass" disks being created. Adjust the recipe as necessary. Excess solution can be store solutions in tightly sealed bottles for 6+ months without degradation.

Eye protection
Latex or Nitrile gloves
Magnetic stir bar
Hot/stir plate
Paper towels
Graduated cylinders for measuring solution volumes
50 mL Erlenmeyer flask or beaker
Droppers/pipettes
0.1 g $HAuCl_4 \cdot 3H_2O$ (hydrogen tetrachloroaurate) (available through Aldrich)
0.5 g $Na_3C_6H_5O_7 \cdot 2H_2O$ (sodium citrate) (available through Aldrich)
1 L distilled water.
25-30 g polyvinyl alcohol (PVA) (available through Aldrich)
(see Setup section for synthesis procedure)

Other suggested materials:

Examples of traditional stained glass
Pictures of a variety of traditional stained glass (windows, Tiffany-style lamps, etc.)

For additional/extension activities, see Extension sections located at the end of the Program Delivery section.

Set Up

Materials Preparation

Note: Large volumes gold and silver nanoparticles/PVA solutions can be made in advanced and stored in tightly sealed bottles. Solutions can be stored for 6+ months. However, it is still advised to make the solutions using the small batch method below and combine the batches for storage.

Synthesis of gold nanoparticle/PVA solution (makes 330 mL, 30-35 minutes)

Complete synthesis procedure with video can be viewed at http://mrsec.wisc.edu/Edetc/nanolab/gold/index.html. Eye protection and latex/nitrile gloves should be worn during synthesis.

Procedure adapted from A. D. McFarland, C. L. Haynes, C. A. Mirkin, R. P. Van Duyne and H. A. Godwin, "Color My Nanoworld," *J. Chem. Educ.* (2004) **81**, 544A.

1. Prepare stock solutions. (These volumes will provide enough solution to do the synthesis below 25 times.)
    a. For 1.0mM solution of $HAuCl_4 \cdot 3H_2O$: Dissolve 0.1 grams of $HAuCl_4 \cdot 3H_2O$ in 500 mL of distilled water. Solution can be made in advance if stored in a tightly sealed, brown bottle.
    b. For 1% solution of trisodium citrate: Dissolve 0.5 g $Na_3C_6H_5O_7 \cdot 2H_2O$ (sodium citrate) in 50 mL of distilled water.
2. Add 20 mL of 1.0 mM $HAuCl_4$ solution to a flask/beaker. Add magnetic stir bar to flask/beaker.
3. Place flask/beaker on hot plate. While stirring, heat solution to a boil.
4. Once boiling, add 2 mL of 1% trisodium dihydrate solution. Continue heating.
5. The gold nanoparticles (a.k.a. colloidal gold) will gradually begin to form during the heating process (approximately 10 minutes).
6. Remove flask/beaker from hotplate when a deep red color is obtained.
7. Slowly, add enough polyvinyl alcohol (PVA) solid to the warm solution to make a 4% (mass/volume) solution (~1 gram for a 22 mL solution). Heat the solution gently to dissolve the PVA. Note: some of the PVA may not dissolve, but solution should be heated, while stirring, until a majority of the solid dissolves.
8. Decant solution into storage bottles (or silicone bake molds if making stained glass pieces at this time). Decanting will help separate the nanoparticles/PVA solution from the undissolved PVA.

Clean up: Rinse glassware. Excess gold nanoparticle/PVA solution can be rinsed down the drain with excess water.

Synthesis of silver nanoparticle/PVA solution (makes 330 mL, 30-35 minutes)

Complete synthesis procedure with video can be viewed at http://mrsec.wisc.edu/Edetc/nanolab/silver/index.html. Eye protection and latex/nitrile gloves should be worn during synthesis.

Synthesis adapted from S.D. Solomon, M. Bahadory, A.V. Jeyarajasingam, S.A. Rutkowsky, C. Boritz, and L. Mulfinger, *Journal of Chemical Education*, **84**, 322-325, (2007).

1. Prepare stock solutions. (These volumes will provide enough solution to do the synthesis below 8 times.)
    a. For 1.0 mM solution of $AgNO_3$: Dissolve 0.017 g $AgNO_3$ in 100 mL of distilled water. This solution can be stored for later use.

   b. For 2.0 mM solution of $NaBH_4$: Dissolve 0.0189 g $NaBH_4$ into 250 mL of distilled water. This solution MUST be made fresh each time.
   c. For 0.3% polyvinyl pyrrolidone (PVP): Dissolve 0.1 g PVP in 33 mL of distilled water. This solution can be stored for later use.
2. Place ice in large container
3. Add 30 mL of the 2.0 mM $NaBH_4$ solution to a flask/beaker. Add magnetic stir bar to flask/beaker.
4. Place flask/beaker in ice bath. Place ice bath on stir plate. Stir and cool the solution for approximately 20 minutes.
5. Slowly, drip 2 mL of 1.0 mM $AgNO_3$ into the stirring $NaBH_4$ solution. Drops should be added at approximately 1 drop / second. Stop stirring AS SOON as all of the $AgNO_3$ solution has been added. The solution should appear yellow, indicating the presence of silver nanoparticles.
6. Remove flask/beaker from ice bath and remove the ice bath from the stir plate.
7. Add 1 drop of 0.3% PVP solution.
8. Place the flask/beaker on the hot plate and heat the solution gently.
9. Slowly, add enough polyvinyl alcohol (PVA) solid to the warm solution to make a 4% (mass/volume) solution (~1 gram for a 32 mL solution). Heat the solution gently to dissolve the PVA. Note: some of the PVA may not dissolve, but solution should be heated, while stirring, until majority of the solid does.
10. Decant solution into storage bottles (or silicone bake molds if making stained glass pieces at this time). Decanting will help separate the nanoparticles/PVA solution from the undissolved PVA.

Preparing the Nanostained glass pieces (15 minutes active time, 2-10 hours drying time)

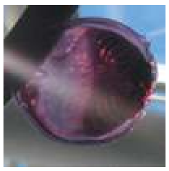
The nanostained glass pieces are made by evaporating the water from the gold and silver nanoparticle/PVA solutions to create plastic disks. Amount of solution needed will vary according to number of disks desired and size of silicone mold. Approximately 3-5 mL are needed to make each muffin-tin sized disk.

1. Pour solution into silicone bake molds. The amount of solution in each mold does not need to be precisely measured. Pour at least enough in to cover the bottom of the mold.
2. Evaporate water from solution. This can be done by leaving the solutions to dry overnight. Depending on temperature and humidity of prep room, some pieces may require more drying time. For more predictable (and shorter) drying times, the solutions can be heated in a toaster oven at 225º F for approximately two hours (or until dry). Thicker disks will require longer drying times.
3. Once dry, remove nanostained “glass” disks from molds. Large batches of disks can be made in advance and stored indefinitely.

Cleanup: Rinse out silicone bake molds. Store disks for later use

Completed disks look like this:

silver nanoparticle stained “glass”

 gold nanoparticles stained “glass” (color can vary from red to purple)

Preparing materials for take-away card (15-60 minutes, depending on quantity)

1. Download and print the take-home card file. Note: There are two files: front and back. The card is double sided, with a specific orientation. The circle drawn on the back side should line up with the empty space on the lower right hand side of the front side. The cards work best when printed on cardstock, and each 8.5” x 11” sheet results in four take-away cards.
2. Using a 1” circle craft punch, punch out the circles on the cards. This will serve as a ‘window’ for the stained glass pieces.
3. Cut lamination sheets into 1.5” x 1.5” squares. Each card will require two lamination squares.
4. Make sample card to share with visitors as they are preparing their own.
5. (optional) Pre-cut some of the nanostained glass pieces into sizes that fit within the circle for visitors to use during assembly/cart demonstration.

Cleanup: Dispose of paper circles. Organize materials for use during demonstration.

Preparing sample take-away card (5 minutes)

1. Gather supplies necessary for one take away card: two 1.5”x1.5” lamination squares, one pre-punched take away card, and one gold and one silver nanoparticle stained “glass” disk.
2. Remove backing from one of the lamination squares and affix it to the take away card so that it covers the punched hole. The sticky surface of the lamination square will provide a nice surface for the nanostained glass pieces to stick to. Turn the card over, so that the sticky side of the lamination square is facing up.
3. Using scissors, cut small pieces off of the gold and silver nanoparticles disks. The pieces should be small enough to fit within the punched circle. Place the pieces on the sticky side of the lamination square.
4. Remove the backing from the second lamination square and affix it to the take-away card, sealing the nanoparticles stained glass pieces between the two lamination squares.

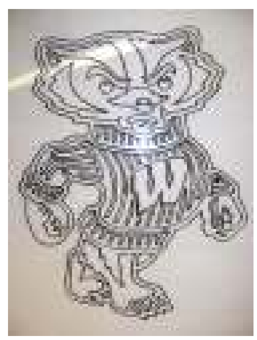
Cleanup: Dispose of backing from lamination squares. Store unused nanoparticles stained glass disks for future use.

Creating the Plexiglass panel (45+ minutes: 15 minutes prep time, 30+ minutes drying time)

1. Select a pattern for the collaborative stained glass panel. The pattern can be anything that the presenter chooses: a preexisting stained glass pattern, a logo, a free hand drawing, etc. A tracing template can be created in a graphics program, such as Adobe Illustrator, or a template downloaded from the Internet. One interesting and easy option is to print and enlarge an existing logo or image and trace it.
2. Trace a pattern on the plexiglass panel with a permanent black marker. Slowly trace over the marker lines with the liquid leading. Draw lines that are approximately 1/8”, with no gaps. If the lines do not meet, the solutions will not be contained. The liquid leading requires at least 30 minutes to dry.

Clean up: Wipe up any excess liquid leading. Make sure caps on liquid leading bottles are tightly secured. Set panel aside to dry.

Examples of patterns traced:



Set up for demonstration: (TIME) 5-10 minutes

For the take-home cards:

Lay out all materials (take-home cards, pre-cut laminating sheets, colored pencils, pre-made nanostained glass pieces (silver and gold disks), and scissors in a convenient way. Containers may be used to organize pieces and prevent colored pencils from rolling off the table.

For the plexiglass panel:

Lay the panel on a table with a white poster board or foam core underneath. The poster board increases the visibility of the pattern and provides a stable surface to transport the panel to a safe place.

Pour ~20-30 mL of each nanoparticle solution into separate plastic cups/containers. (Store additional solution nearby.) It is helpful to have a few containers of each solution so that several visitors at a time can add to the stained glass panel.

Place droppers, gloves, paper towels and goggles on the table.

Program Delivery

Time: 20-30 minutes

Safety:
Visitors' use of chemicals should be supervised by a trained staff member.

PVA, gold nanoparticles and silver nanoparticles are not known to be toxic, but exposure to skin and eyes should be avoided. If solutions come into contact with eyes or skin, flush with water.

Gloves should be worn by both visitors and staff when handling chemicals. If a visitor has latex allergies, nitrile gloves should be worn. Safety glasses should be provided as well.

Nanoparticle-stained "glass" disk (and pieces of disks) should not be handled extensively. The PVA used to make the disks is soluble in water. Sweat from handles will cause the disks to dissolve. For this reason, the nanoparticle-stained "glass" pieces should not be de-laminated from the card.

It is suggested that safety scissors are used for cutting the nanoparticle disks.

Procedure and Discussion:

A Power Point presentation has been provided to accompany the suggested script below. The presentation takes 10-13.

[Slide 1]
Introduction

[Slide 2]
Here I have images of two different groups of people. On the left, a medieval artists' studio…specifically one with stained glass artisans hard at work. On the right, you see a group of scientists working in the lab. So one picture shows workers in the 1400s and 1500s, while the other show workers today. What do you think these two groups of people have in common? Any ideas? **[take suggestions from the audience]** Great ideas…

[Slide 3]
Both pictures show NANOTECHNOLOGISTS hard at work!!

[Slide 4]
Nanotechnologists??! To figure out how that at all could be possible, let's talk about what nanotechnology is. Here's a definition that the folks in Washington, DC use. **[read slide]** Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

But what does all that really mean?

[Slide 5]
Well, I think for our purposes, nanotechnology can be summarized in three points. **[read point 1, 2, and 3]**
1. The nanometer is extremely small.
2. At the nanometer scale, many materials behave differently.
3. We can harness this new behavior to make new technologies.

[Slide 6]
But how small is "extremely small"? Well, here I have a meter stick **[hold up meter stick]**—it's about the height of an adult bicycle or the height of 7 year old. I'm going to imagine cutting this meter stick into different sized pieces:
First, into 10 equal pieces…at that point, each piece is 1/10th of a meter, and it is about the size of my iPod.
If I cut this meter stick into 100 pieces (with each piece being a 1/100th of a meter) each piece will be about the size of a lady bug.
If I take the same meter stick, and instead cut it up into 1,000 pieces, each piece would be about the same size as a grain of sand. Grains of sand are pretty small…but I can still see those with my eyes.

[Slide 7]
Let's go even smaller….if I cut this meter stick into a MILLION pieces, (so each piece is one MILLIONth of a meter), the pieces will be about the size of red blood cells. I can't see those with my eyes, but using a light microscope (like the ones you may have used in biology class) will let me see them. But….these blood cells are still ONE THOUSAND times bigger than objects on the nanoscale.

[Slide 8]
To "nanosize" this meter stick…I'd need to cut this stick into one BILLION pieces. Things like viruses and DNA will be about the size of each one of my nanometer stick pieces. Other things that are nanosized are buckyballs and carbon

nanotubes---two recently discovered forms of carbon. And just a little smaller than one nm we have atoms—those little tiny things that make up everything around us.

So….what do all of these nanosized things have to do….

[Slide 9]
….with these artisans in the 1400s and 1500s? Well, it turns out these stained glass artisans are an early example of UNKNOWING nanotechnologists! When making beautiful colored glass in their shops, the artists would mix in coloring agents: chemicals like gold chloride, silver nitrate and other metal based compounds. . When the powders dissolved in the molten glass, the artists witnessed a beautiful color change. The gold compounds caused the molten glass to turn red. The silver compounds turned the glass yellow. But why?   The process they used accidentally created tiny nanoparticles of gold and silver in the glass….

[Slide10]
But wait a minute… gold isn't red—it's yellow and shiny. People wear it as jewelry. Same goes for silver—in bulk, it ' gray and shiny.

[Slide 11]
But when we get down to the nanoscale, the tiny particles of gold and silver CHANGE COLOR. Nanoparticles of gold are RED, and nanoparticles of silver are YELLOW. Size really does matter!! Because of their extremely small size, the particles interact differently with light than gold and silver we see with our eyes, so they appear a different color.

[Slide 12]
Well, nanoparticles of silver and gold can be all sorts of colors. If the stained glass artisans had been able to carefully control the size of the nanoparticles of gold, they could have had green and yellow as well.

[Slide 13]
Changing the size and shape of the silver nanoparticles creates different colors, too. Making the particles smaller causes them to appear blue. Changing the shape of the particles from round to triangular causes them to appear red.

[Slide 14]
These tiny particles are used today for lots of cutting-edge procedures. For instance, scientists are using gold nanoshells (tiny beads of glass coated in gold) as a possible cancer therapy. Scientists at Rice University have figured out a way to get these nanoshells to concentrate ONLY in the cancerous tumor cells. A patient's body is then exposed to infrared light, which pass through skin and muscle tissues. The shells heat up, causing the tumor cells to heat up, and

eventually die. Because there aren't any nanoshells in the healthy cells, the infrared light doesn't have any effect on them.

[Slide 15]
A little closer to home, nanoparticles of silver are being added to a bunch of consumer products. Silver has long been known to kill bacteria. Infected wounds were treated with solutions of silver ions, and silver solutions used to be added to the eyes of newborn babies to kill bacteria. But now, companies are imbedding nanoparticles into materials like socks and athletic apparel. And even plastic food containers, as shown here. The nanoparticles don't wash off as easily as a solution would, so the product can maintain the antibacterial properties for longer. If anyone has these containers, now you know it is the silver nanoparticles that give them their yellow hue!

[Slide 16]
Okay, I've talked enough, and we promised you'd get to take home some nanostained items today. So, now it's your turn. "You" are somewhere in between these two scenes: no need for hot molten glass, and you don't have to wear one of these interesting looking suits!

Before we started, I made up some solutions of gold and silver nanoparticles in the laboratory **[hold up solutions]** and some nanostained "glass" **[hold up PVA disks]**. It's actually not glass but plastic. After making the solutions of the nanoparticles, we added a polymer, or plastic, so that when the solutions dried, they would dry as these hard disks.

[Slide 17]
I would like to invite everyone up to the tables to help make a collaborative stained glass panel, or to make a mini stained "glass" window to take home with you.

[Explain how to do each component. Use visuals, and perform each task to give visual learners an opportunity to see the procedure for each.]

[Slide 18]
Thank you!

After the presentation, invite the visitor to participate in the hands-on activities.

1. Visitors can choose to make a small piece of stained "glass" by snipping off a small piece and laminating it into one of take-home cards. Walk visitors through the steps of creating the take-home card. (See "Preparing sample take away card" section under Setup section for explicit directions.) Show that when the card is held up to the light, the piece of nanostained glass resembles a real piece of stained glass. Remind visitors of the connection to medieval artisans – who

were unknowing nanotechnologists. Visitors may take their piece of laminated stained “glass” home as a souvenir.

2. Visitors can choose to help make a collaborative stained ”glass” panel. Show visitors that by using a glass dropper like a paint brush, they can fill in the design with the nanoparticle solutions. If applicable, explain that the panel will be allowed to dry overnight and then it will be hung in a specific place in the museum.

Tips and Troubleshooting:

For the take home cards:

Visitors often struggle with peeling the backing off the lamination squares. Double-sided tape can sometimes assist in removing the backing. Staff members can help remove the backing, or younger visitors (or visitors with limited dexterity) can be paired with visitors who are able to peel off the backing.

Small – 1 to 10 mm long – nanostained “glass” pieces work best for lamination in the card. Providing pre-cut pieces may encourage visitors to cut pieces similar in size to the sample pieces.

For the collaborative stained “glass” panel:

If visitors put too much solution in a section of the pattern, it will overflow into adjacent sections. This can be messy. Encourage visitors to use just enough nanoparticle/PVA solution to fill the section.

Common Visitor Questions

1. Why does the color change at the nanoscale? How does the color change in the gold and silver particles?
   When light shines on the surface of a metal, some of the light waves *propagate* (move) along the surface of the metal and give rise to a *plasmon* – a group of electrons moving back and forth in sync across the surface of the metal. The plasmon is said to be in resonance with light when the frequency of the plasmon's oscillation (the rate at which the electrons are moving back and forth) is the same as the frequency of the light that produced it. The oscillating electrons then emit light of their own at the same frequency, producing the color that you see.

2. How were stained glass windows created?
   Artists melted sand to make glass, and added chemicals for color. Pieces of colored glass were cut roughly from large sheets to the approximate sizes and shapes needed for the desired pattern in the window being

created. Artisans then used a diamond grinder to grind down the glass to its desired shape. In medieval times, the pieces of glass were then assembled into a window using lead strips (called lead came) to hold the glass in place. The joints between the glass and the lead strips were soldered together, to fill in the gaps between the glass and the premade lead came. Lastly, the window was glazed to strengthen all of the glass/lead joints.

Later, a new method was created, called the LaFarge Method, which allowed artisans to create more intriciately detailed patterns. Copper foiling was used in place of the lead came. Since the copper foil was more malleable, it could be fitted around the smaller, more delicate pieces.

3. In what some other examples of the interconnection between science and art?
   Both fields are based on experimentation, process and outcomes. Artists have long experimented with different media for pieces, as well as different techniques to produce works of art. Scientists perform experiments to better understand a phenomenon they are studying.

   Scientists and artists have even partnered to help each other in their works. In the 1700s, scientists experimented and created paints that were longer lasting and non-toxic, since many of the paints used in that time contained lead. In the late 1870's, a new type of paint that could be stored in tubes was developed. This discovery gave artists the freedom to leave their studios and take their canvases and paints outside—which ultimately lead to the Impressionist Art Movement in Paris.

   Artists have also helped scientists do their work better. Artists have long worked at medical and scientific illustrators, depicting anatomy, nature and even things too small to be seen with the naked eye

4. Who are some famous medieval artisans or scientists?
   A comprehensive list of renaissance artists can be found here:
   http://witcombe.sbc.edu/ARTHrenaissanceitaly.html#general

   A list of scientists in the middle ages can be found at:
   http://en.wikipedia.org/wiki/History_of_science_in_the_Middle_Ages

   A list of pre-21st century female scientists can be found:
   http://en.wikipedia.org/wiki/List_of_female_scientists

5. Who are some more recent stained glass window artists?
   Judith Schaechter, Clara Driscoll, Tony Holloway, Frank Lloyd Wright, Louis Comfort Tiffany and John LaFarge are just a few well known stained glass artists from the 20th century.

6. Can I take my stained glass piece out of the laminate?
   No, please do not remove the stained glass from the laminate. The stained glass is made of a material that dissolves in water. Extended contact with the sweat from your hands is enough to cause piece to dissolve.

7. Is this real stained glass?
   No. The “glass” created today is actually made of polyvinyl alcohol (PVA), which is a type of plastic. We use PVA because it does not have to heated to extremely high temperatures like glass. Also, the PVA stained “glass” is not fragile like glass.

Going Further…

High school groups may want to follow up this activity by making gold and silver nanoparticles in their classrooms. Procedures can be found on the UW-MRSEC website under the video lab manual section.

http://mrsec.wisc.edu/Edetc/nanolab/gold/index.html
http://mrsec.wisc.edu/Edetc/nanolab/silver/index.html

Plasmon resonance websites:
http://en.wikipedia.org/wiki/Plasmon
http://www.qub.ac.uk/schools/SchoolofMathematicsandPhysics/con/plasmon/sp1.html
http://www.ifa.hawaii.edu/~kaiser/wavemovies/movies/packet.gif
(Example of what a wave packet looks like to show a plasmon surface motion website above)

Stained Glass resources:

http://www.artic.edu/aic/education/sciarttech/2d3.html
http://www.uwm.edu/Dept/ArtHistory/StainedGlass/history.htm
http://www.thestorefinder.com/glass/library/history.html
http://www.discovernano.northwestern.edu/artgall
http://en.wikipedia.org/wiki/Stained_glass

Armitage, E. Liddall*, Stained Glass History, Technology and Practice*, Leonard Hill Books Limited (London), 1959.

Chang, Kenneth. “Tiny is Beautiful: Translating ‘Nano’ Into Practical.” New York Times 22 Feb 2005: Science. (available at http://www.nytimes.com/2005/02/22/science/22nano.html?ex=1266814800&en=4ea37d77d2651a3f&ei=5090&partner=rssuserland, accessed June 13, 2008.)

Clean Up

Time: 5-10 minutes

Return gold and silver nanoparticle solutions to airtight containers. Solutions can be stored for 6+ months without noticeable degradation.

Organize and store the materials for the take-home cards.

Transport collaborative stained glass plexiglass panel to a safe place to dry. The panel will take approximately 3-4 hours to dry. A frame can be built (or holes drilled in the panel) to display it. If the panel will not be displayed, the solutions can be rinsed off of the panel before they dry, to allow the plexiglass panel to be re-used at another time.

Wash hands and clean any surfaces that may have come into contact with the solutions.

Extension Activity: Collaborative Suspended Sculpture

This is an extension activity that can be used in the presentation of this program.

Materials

metal conduit tubing or irrigation tubing (sold in approx 18-24' sections, available at local hardware stores, number of sections variable)
fishing line (available at local hardware stores)
duct tape (available at local hardware stores)
100 (at least) gold nanoparticle stained disks (see Setup for preparation of disks)
100 (at least) silver nanoparticle stained disks (see Setup for preparation of disks)
galvanized steel wire (available at local hardware stores)
wire cutters (available at local hardware stores)
pliers (available at local hardware stores)
cotton gloves (to wear while piercing disks, to prevent poking yourself with wire)
containers to organize the disks (optional)
100' rope
wooden dowel or painted yard stick

Set up:

Making the conduit/irrigation tubing frame (30+ minutes):

To create the frame of the sculpture, you will want to find a large space with lots of natural light, if possible. The sculpture looks best if suspended in an open space. (see pictures below)

With fishing wire or duct tape, secure one end of the tubing to a stable anchor point. An anchor point can be created using a painted yard stick or wooden dowel suspended by rope.

Once one of the ends is secure, begin twisting the tubing in different ways. Every few feet use the fishing line to tie the tubing to itself and create a structure (see pictures below). Each structure will look different. This prep work should be done before the visitors arrive. Continue this twist and tie process until the entire length of the tubing has been used.

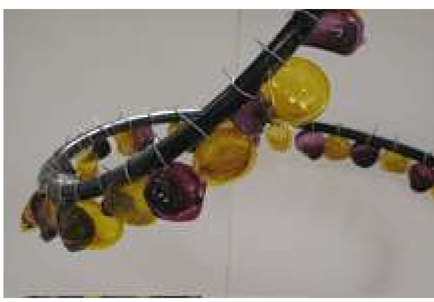
The remaining end can be secured to another part of the conduit/irrigation tubing, or allowed to float freely.

Preparing the disks for hanging (15 minutes):

Galvanized steel wire will be used to hang the disks on the conduit/irrigation tubing frame.

Using wire cutters, Cut galvanized wire approximately 3" long. Cut as many wires as you have disks.

Pierce nanoparticle stained "glass" disks with the end of a wire and thread disk onto wire. Note: Be careful not to pierce your skin while pushing wire through nanostained disk. Cotton work gloves are helpful in preventing this.



Irrigation tubing **Metal conduit**

Before visitors arrive, hang a few disks on the tubing sculpture. Hold the disk close to the tubing frame and bend the galvanized wire around the conduit/irrigation tubing to attach the disk to the sculpture. Carefully twist the two ends of the wire together to secure the disk in place. Pliers can be used to help twist the wire ends together.

Program Delivery:

The complete sculpture (adorned with nanoparticles stained glass disks) can be built before visitors arrive, or it can be built as a collaborative art experience.

If used as a collaborative art experience:
After the program presentation, add the sculpture as a possible hands-on activity. Invite visitors to hang a disk on the sculpture. Instruct visitors to hold disk close to the tubing frame. Demonstrate how to bend the galvanized wire around the conduit/irrigation tubing to attach the disk to the sculpture. Have visitors carefully twist the two ends of the wire together to secure the disk in place. Pliers can be used to help twist the wire ends together.

Tips and Troubleshooting

The tubing ends of the metal conduit can be sharp. Use care when handling and discourage visitors from touching the end.

The tips of the wires can be sharp. Encourage visitors to use caution when wrapping the wires around the conduit/irrigation tubing frame.

Clean up

Remove conduit/irrigation tubing frame from anchor point. Remove all disks from frame by unwrapping wire from around tubing. Cut fishing line holding conduit/irrigation tubing. Wrap tubing into a coil for storage. Store disks and conduit/irrigation tubing for future use.

Extension Activity: Nanostained "glass" sun catchers

Materials:

sample sun catcher
contact paper/laminating strips (pre-cut to desired size)
pre-made gold nanoparticles/PVA disks (see Setup section for preparation)
pre-made silver nanoparticles/PVA disks (see Setup section for preparation)
scissors
hole punchers
yarn (cut into 6-8 inch lengths)

Set up:

Preparing a sample suncatcher (5 minutes)

1. Take a precut piece of contact paper and fold it in half.
2. Peel off the paper backing halfway (to the fold).
3. Cut different shapes from pre-made nanoparticle stained glass pieces.
4. Arrange the pieces on the exposed sticky side of the contact paper to create a pattern.
5. Remove the rest of the paper backing from the contact paper, and fold the blank side over the side with the pattern. The fold will turn out best if you press the sides together starting at the fold and work toward the open edges, not the other way around. The contact paper is re-sealable, so if the fold doesn't come out well, you can peel it open and try again.
6. Punch a hole along one edge of sun catcher, wherever you want the top center to be.
7. Thread a piece of yarn through the hole, and tie into a loop.
8. Suggested: add a tag to the sun catcher to indicate that "Gold nanoparticles are red" and "Silver nanoparticles are yellow".

Arrange materials in a way that allow for easy use by visitors.

Program Delivery:

After the program presentation, add making a sun catcher as a possible hands-on activity. Demonstrate how to make the sun catcher (using the steps in "Preparing a sample sun catcher"). Have visitors fold the contact paper strip in half, and peel off the backing to the fold. Demonstrate that the nanostained glass pieces can be cut into different sizes and arranged on the stick side of the contact paper. Allow time for visitors create their patterns. Once completed, instruct visitors to continue to peel off the paper backing. Once the paper backing has been removed, demonstrate folding the contact paper over onto itself, to create the sun catcher. Instruct visitors to punch a hole near the top of one edge and thread a piece of yarn or string through the hole. A tag can be added to the string to reinforce that "Gold nanoparticles are red" and "Silver nanoparticles are yellow".

Examples of sun catchers made with nanoparticles stained glass disks.

Tips and Troubleshooting

Some hole punchers are not sharp enough to punch through the contact paper. Test the hole puncher prior to doing the activity on the floor.

This activity has the potential to use up a lot of nanoparticles stained "glass" disks. The instructor may want to precut small pieces of nanoparticle stained "glass" to encourage visitors to use smaller amounts.

Clean up

Organize and store unused materials.

Universal Design

This program has been designed to be inclusive of visitors, including visitors of different ages, backgrounds, and different physical and cognitive abilities.

The following features of the program's design make it accessible:

[X] 1. Repeat and reinforce main ideas and concepts

- The overarching main idea is presented at the beginning of the program, and reinforced by the hands-on activities.
- The program provides verbal, visual and tactile entry points into the program's main message and learning objectives.
  - The presenter provides a verbal and visual explanation of the nanoscale and the connection of stained glass and nanotechnology. The hands-on activities provide a tactile explanation of the connections between nanotechnology and stained glass.
  - The size of the nanoscale is conveyed verbally during the presentation as well as visually, by the graphics in the presentation.
  - The differences in how nanoscale things behave are explained verbally and visually (in the presentation slides and through the observation of the nanostained glass pieces).
  - The interconnection between art and science is highlighted verbally and visually in the presentation. The interconnection is also demonstrated with the hands-on creation of a nanostained "glass" window or sculpture.
- The take-away card reinforces the main ideas and concepts visually and verbally.

[X] 2. Provide multiple entry points and multiple ways of engagement

- The program engages visitors with two (or more) hands-on activities, and a guided discussion that helps them understand the connections nanotechnology today with its historical use by stained glass artisans.

[X] 3. Provide physical and sensory access to all aspects of the program.

- The presenter verbally explains and physically demonstrates all aspects of the hands-on activities. Brief written directions are also provided in the presentation slides. Presentation of directions appeals to many different learners.
- The additional hands-on activity "Nanostained glass sun catchers" (provided in the Extension sections) allows for visitors with limited manual dexterity to create a nanostained glass window similar to one created in the take away card.
- The presenter can vary the pace of the program to suit audience, providing extra time for working or additional discussion when necessary.

To give an inclusive presentation of this program:

1. Left handed, right handed and safty scissors should be provided.

2. Supplies for the hands-on activities should be arranged to accommodate visitors of all abilities.
3. Print outs of presentation slides (and accompanying talking points for each slide) can be provided.

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