Teacher's Preparatory Guide

Design Challenge: Incorporating Shape Memory Alloys into Rube Goldberg Devices

Purpose
To encourage students to compare and contrast science and technology; experimental design and industrial design; and physics and its impact on nanotechnology. The students will be able to analyze and reflect on the forces, motion and energy transformations that can be shown by a Rube Goldberg Device and to experience the impact that Nitinol wire has on the device.

Time required:
Two 50 min class periods for project instructions
Four weeks for Rube Goldberg design and testing (Provide at least two 50 min class periods for students to plan and work on device. Other work must be done outside of class time.)
One 50 min class period for presentation of devices

Level:
Upper middle school and high school. Younger students could be assigned a simple Rube Goldberg device and shown how Nitinol wire works.

Teacher Background
A Rube Goldberg machine is a complex apparatus that performs a simple task in an indirect and convoluted way. The term also applies as a classification for a generally over-complicated apparatus or software. It first appeared in *Webster's Third New International Dictionary* with the definition "accomplishing by extremely complex roundabout means what actually or seemingly could be done simply."

Nitinol is a shape memory alloy. It will spring back to its original shape when heated. The Nickel and Titanium atoms in the Nitinol wire are in an ordered arrangement, or crystal structure. But nothing's perfect. There are mistakes in the way the atoms are arranged, and these mistakes are called defects. These mistakes could be missing atoms, or extra atoms that are trapped in there. When Nitinol wire is at room temperature, it is very easy to bend. Heating it causes it to change to a rigid phase with a different crystal structure. When it cools back down, the atoms go back to exactly their original positions, including defects. These mistakes are a good thing. It's the position of the defects in the wire that makes it come back to the same shape every time it is cooled and heated.

Materials

Copies of "The Story of Nitinol", Comparison of Wire Activity, Challenge Instruction Sheet, and Parent Letter for each student.

Internet connection for Honda cog commercial

For Comparison of Wire Activity: 5 cm long pieces of 3 to 5 different types of wire. One of the wires must be Nitinol. Other materials needed include small beakers, water, ice, hot plate, candle, matches, tongs, plastic container, and thermometer.

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Container of materials for each group. (What follows is a list of materials that I used with my classes but it could be any combination of available materials. Styrofoam blocks, large tongue depressors, small magnets, bathroom size paper cups, ping pong ball, string or cord, small piano hinges, plastic spoons, regular mouse traps, marbles of any size, small wooden spools, small tongue depressors, rubber bands of various sizes, regular drinking straws, metal spring of various sizes, flat sticks of balsa wood, different diameters of dowel rods, helium balloons, pulleys, tissue paper and graph paper.

Ideas for task can be found at http:// www.rube.iscool.net

Advance Preparation

1. Decide on task to be accomplished by the Rube Goldberg Device and produce a rubric and instruction sheet. (Sample instruction sheet and rubric are attached.)

2. Purchase materials to be used for device or construct a list of materials that can be used. In addition purchase the Nitinol wire needed for the activity. (A list of materials that were used for this activity is on student instruction sheet.) (Web addresses for purchase of wire follow in resource section.)

3. Provide enough copies of instruction sheets and parent letters for each student and put together a kit of material for each group.

4. Provide instruction sheets and prepare materials for the "Comparison of Wire" activity. (Copy of activity attached)

Safety Information

Since much of the work will be done outside the class a parent letter will be attached to the instruction sheet. This form will be signed and returned by the student. All students have a safety contract already signed and on file. (Copy of parent letter attached)

Caution students during the Comparison of Wire activity to be careful with the heated water and wire.

Safety goggles should be worn during the wire activity and the demonstration of the devices.

Directions for the Activity

1. Show students some items and ask students what went into developing these products. (Make sure that at least one of the products is a nano product. Examples of nano products can be seen at www.nnin.org/edu.html)

2. Ask students to discuss the following questions:

- Why do you think these products were developed? (Because they were needed, because they were wanted, because they solved a problem, etc)
- What do you think went into the producing of these products? (Someone had to come up with idea, design product and test it.)
- What determines what new products are developed? (Consumer wants and needs.)
- Do you think there is a process that goes into producing new products? (yes, product design)
- What are science experiments designed to do? (To solve a problem or to answer a question.)

3. Distribute to students article "The Story of Nitinol". (Copy of article with source is attached)

4. Divide class into groups and have them complete the comparison of Wire Activity. (Copy of activity is attached. Activity was adapted from the following web site. http://csats.psu.edu/files/GREATT/MemoryMetals-Nitinol/Memory_Metals.doc)

5. Discuss Comparison of Wire activity. Point out the history and characteristics of the Nitinol wire.

6. Show student the Honda Rube Goldberg cog commercial at the following address: http://www.jugglingcats.com/video/the_cog1.htm)

7. Distribute the Challenge Instruction sheet and go over. (Copy of sheet attached)

8. Provide at least two 50 min class periods for students to plan and work on device. (I also stayed late at school a couple afternoons a week so that students could work with their group at school.)

9. Students will turn in the following items on _____________. A CD/DVD with their two minute

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commercial, a one page summary of how a shape memory alloy works, a diagram of their Rube Goldberg device with all energy transformations listed and their Rube Goldberg Device.

Procedure (from Student Activity Guide)

(Copy of the student activity instruction sheet that I used is attached)

Cleanup:

If you allow groups to work in your room you will need to provide containers for students to put trash in. I also had students turn in all their extra materials when they turned in their device. I had containers set out on the lab table for them to put extra pieces in.

Worksheet (with answers)

Copy of Comparison of Wire Activity is attached with answers.

Assessment

Project will be judged based on rubric. (Copy of rubric is attached).
Bonus points will be decided by outside judges. Contact your local university/college to find judges for the commercials. Ask the judges to rank the commercials that they evaluated. Depending on the number of commercials they should be able to evaluate at least six.

Resources:

To learn more about nanotechnology, here are some web sites with educational resources:

Nitinol sources- specify a diameter of around .029 "and a transition temp of about 50 degrees C
http://www.teachersource.co
http://www/imagesco.com/nitinol/wire.html
http://www.smallparts.com/products/
http://robotstore.com

Additional information on shape memory alloys:
http://www.imagesco.com/articles/nitinol/01.html
http://www.cs.ualberta.ca/~database/MEMS.sma_mems.sma.html
http://www.nnin.org

National Science Education Standards

Science as Inquiry
1. Abilities necessary to do scientific inquiry
2. Understandings about scientific inquiry.

Physical Science
1. Motion and forces
2. Conservation of Energy
3. Interactions of Energy and Matter

Science and Technology
1. Abilities of technological design
2. Understanding about science and technology

Science in Personal and Social Perspectives
1. Environmental quality
2. Science and technology in local, national, and global challenges

History and Nature of Science
1. Science as a human endeavor
2. Nature of scientific knowledge
3. Historical perspectiv

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Rube Goldberg Device Challenge Instruction Sheet

Background: You work for the "Physics is Fun" public relations firm and you have been hired by the Nanotechnology Industry to produce a two minute commercial that shows a Rube Goldberg device that will launch a ping pong ball at least one meter. The Rube Goldberg device must be started by the activation of a Nitinol wire. A Rube Goldberg device is a device that performs a simple task with a chain reaction of events.

Goal: Your team must design and produce a device that will launch a ping pong ball at least 1 meter when activated by a Nitinol wire.

Items to turn in:
Rube Goldberg device (one per team)
Diagram of device showing all energy transformations (one per team)
CD/DVD with two minute commercial (one per team)
One page essay on how a shape memory alloy works (one per person)

Date:
All items must be turned in on ________________________

Rules:

1. Machine must complete the main task which is to launch a ping pong ball at least 1 meter.
2. Machine must fit within the dimensions 3 ft x 3 ft x 3 ft.
3. Machine must run a minimum of 15 energy transformations.
4. Machine must not run longer than 3 minutes.
5. Any flying or loose objects must remain inside the machine except for launched ping pong ball.
6. No explosives or hazardous materials allowed.
7. Only heat source used to activate Nitinol wire allowed.
8. No external or AC power.
9. The machine must be determined safe by the teacher.
10. Only materials given to group can be used except for glue or tape.
11. Only human intervention allowed is activation of Nitinol wire.
12. Energy Transformations allowed are mechanical or thermal. Examples are: mechanical-kinetic/potential, thermal and magnetic
13. Materials given to each group include:
    - 4 inch by 4 inch Styrofoam block
    - 17 large tongue depressors
    - 2 small magnets
    - 8 bathroom size paper cups
    - 1 ping pong ball
    - 2 meters of any type of string or cord
    - 2 small piano hinges
    - 6 plastic spoons
    - 2 regular mouse traps
    - 25 marbles of any size
    - 2 small wooden spools
    - 50 small tongue depressors
    - 15 rubber bands of various sizes
    - 10 regular drinking straws
    - 3 metal springs of various sizes
    - 15 flat sticks of balsa wood a meter each in length
    - 15 square sticks of balsa wood a meter each in length
    - 4 different diameters of dowel rods
    - 8 regular helium balloons
    - 6 different pulleys
    - 1 sheet tissue paper
    - 1 sheet of graph paper
    -

*All rules are subject to changes or clarification by the teacher.

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Rube Goldberg Device Challenge Rubric

Item	Points each	Maximum points	Points Awarded	Comments
Device				
Energy Transformations completed on Device	2 points each	30 points		
Task completed in 3 minutes or less	2 points	2 points		
Machine has a theme that runs throughout device	2 points	2 points		
Diagram				
Each transformation listed in order	2 points each	30 points		
Names of each team member included on graph	2 points	2 points		
Commercial				
Turned in on CD	2 points	2 points		
From 2 to 2.5 minutes long	2 points	2 points		
Shows device activated with Nitinol wire	10 points	10 points		
Shows completed task	10 points	10 points		
Essay on Smart Memory Alloy	10 points	10 points		
Bonus Points				
Deductions				
		Total Points		

<u>Bonus Points</u>
Ping pong ball went at least 1 meter 10 points
Best commercial in class 10 points
Second best commercial in class 5 points

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Overview: In this activity, you will determine which of a set of wires is a unique metal alloy called Nitinol. Nitinol is called a shape memory alloy (SMA) because it can "remember" its original shape under certain conditions after being bent, twisted, or stretched out of shape.

Objectives: Students will

1. Know that a shape memory alloy "remembers" original shape after being deformed.
2. Know that Nitinol can undergo phase changes while in the solid state, and these phases are temperature dependent.

Procedures:

Part1:

1. Read about the history of Nitinol wire and answer questions below.
   a. What two metals make up Nitinol? (Nickel and Titanium)
   b. What is NITINOL an acronym for? (Nickel Titanium Naval Ordnance Laboratory)
   c. What larger project was William J. Buehler working on when he discovered something unique about nickel-titanium alloys? (Developing metallic materials for the nose cone of the U. S. Navy Polaris reentry vehicle.)
   d. What initially compelled Buehler to drop one of the cooled bars on the concrete floor? (He accidentally dropped a nearly cooled bar on the floor and it sounded different than the hot bars.)
   e. Why did Dr. Muzzey heat the demo wire with his pipe lighter? (Around a meeting table he was smoking a pipe and decided to put the lighter to the wire.)
   f. How do your answers in questions in d and e show that doing science involves curiosity, imagination, and creativity? (They were both accidental discoveries about Nitinol's characteristics.)
   g. Provide evidence from the reading that shows how science is NOT a solitary activity. (Buehler first worked with Nitinol, Muzzey discovered shape memory, Wang discovered how the shape memory property works.)

Part 2:

1. Your teacher has given your group a container with the following materials: Pieces of wire, beakers, water, ice, hot plate, candle, matches, tongs, plastic container, and thermometer.
2. Prepare two beakers of water-one that contains hot water (80º C or higher) and another that contains ice water. Deform each of your pieces of wire (bend, twist, pull, reshape, etc), place them in the hot water and record below your observations

Only the Nitinol wire should change shape.

3. Using tongs or tweezers, try to bend the wire while it is still in the hot water. Are any of the wires easily deformable at this temperature? Yes or No
4. Now remove each piece of wire from the hot water USING TONGS or tweezers and drop them into the ice water WITHOUT deforming them. Observe the wires for a few moments as it cools down. Record your observations below.

All of the wires should not change

5. Decide which of the wires the Nitinol wire is and check your choice with the teacher.
6. Read the information below:

How Nitinol Works

We're all familiar with such phase changes as the melting of ice or vaporization of water. Less known is that such phase changes can occur when both phases are solid such as the change from graphite to diamond. Many materials undergo such transformations, which involve

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rearrangement of the position of atoms, molecules, or ions within the crystal lattice. In a non-memory metal the strain of deformation is absorbed by the rearrangement of the crystals, and it is impossible to get the crystals back into exactly the original position. In Nitinol, the crystals stay in place; the atoms within the crystals rearrange themselves, and the distorted object reverts to its original shape.

Part 3:

1. Try to change the pre-set shape of your piece of Nitinol wire by holding it into a desired shape over a candle. DO NOT DO THIS WITH YOUR BARE HANDS! Follow direction below:

a. Choose a simple shape, such as a loop or a horseshoe, and use your forceps to hold your piece of Nitinol wire in this shape. Hold both ends to maintain shape.
b. Hold the wire in place as you place it in the flame. The wire will initially resist and attempt to return to its original shape, but you must continue to apply pressure and keep the wire held in its new position.
c. As soon as you feel a release of tension as you are heating, you may remove the wire from the flame.
d. Let the wire cool down before touching it.
e. After the wire is completely cooled down straighten the wire out.
f. Place the wire in the container of hot water from part 2. Does your wire remember the shape from Part 3? (If students heated the wire correctly in b and c it should remember the shape.)

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Parent Letter

As part of your child's requirements for fall semester of _______________ is the completion of a Design Challenge project. The purpose of this project is for students to be able to analyze and reflect on the forces, motion and energy transformations that can be shown by a Rube Goldberg Device and to experience the impact that Nitinol wire has on the device.

To prepare your students for this project I have shown them examples of Rube Goldberg devices, a Honda car commercial at www.jugglingcats.com/video/the_cog1.htm , assigned your child to a group of students, provided an opportunity for students to learn about nitinol wire, and provided each group with a variety of materials

Students have been challenged to produce a Rube Goldberg device that will launch a ping pong ball at least one meter, and must also produce a diagram of their device and a commercial using their device. This must be turned in on ____.

This letter is to inform you of the requirements of the project and to also inform you that even though time will be provided for groups to work in my room after school two days a week, some groups may choose to work outside of school. Please help your child be aware of safety issues involved in working with equipment and working at other student's homes.

Please sign and date this form and return with your child by ________________________

Child's Name____

Parent Signature_______________________________________

Date_____________________________

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<u>**The Story of Nitinol**</u>

A reading taken with permission from
Kauffman, G. B. and Mayo, I. ***Chemistry and History: The Story of Nitinol: The Serendipitous Discovery of the Memory Metal and Its Applications.*** Chem. Educator 1997, 2(2): S1430-4171 (97) 02111-0, 21 pp., DOI 10.1007/s00897970111a, Electronic Journal.

In January 1958 William J. Buehler, a metallurgist at the Naval Ordnance Laboratory (NOL) had completed research on a series of iron-aluminum alloys. Buehler, born in Detroit, Michigan on October 25, 1923, had received his Bachelor of Science degree in chemical engineering (1944) and his Master of Science degree in metallurgical engineering (1948) from Michigan State University at East Lansing.

The "between-projects boredom" began to set in for Buehler after completing the iron-aluminum alloy project:

> It was at this point that lady luck played a key role. I found within the U.S. Naval Ordnance Laboratory an ongoing materials project which had the goal of developing metallic materials for the nose cone of the U.S. Navy Polaris reentry vehicle. The in-house project was under the direction of Mr. Jerry Persh, an aerodynamicist. I was able to attach myself to this project, and my initial task was to provide physical and mechanical property data on existing metals and alloys for computer-assisted boundary layer calculations. These calculations were to simulate the heating, etc. of a reentry body through the earth's atmosphere. My informational role in this project very quickly became somewhat boring, and I almost immediately began to think in terms of possibly tailoring newly developed alloys that might better satisfy the drastic thermal requirements of the reentry body.
>
> My first wife and I separated, and I spent a tremendous amount of time working in the laboratory…you might say it's a good feature that came out of a disastrous situation. I had lots of time at that point…in the state of Maryland the law required a three-year waiting period of separation before formal divorce could be handled. During that three-year period I literally worked day and night. Many days I would get up at 4 o'clock in the morning, go to the lab, and not go home until 11 o'clock at night. Between working at the laboratory and playing, I really didn't do anything other than eat or sleep.

Buehler selected approximately sixty…alloys [to] study. This number was then reduced, for various logical reasons, to twelve alloy systems. One of the systems, [a] nickel-titanium alloy, immediately exhibited considerably more [fatigue-, impact-, and heat-resistance] than the other eleven alloys. In 1953 Dr. Harold Margolin of New York University and his associates had carried out some studies on phase changes of nickel-titanium alloys but had sensed no uniqueness among them.

In 1959 Buehler…named [this nickel-titanium alloy] NITINOL (**Ni**ckel **Ti**tanium **N**aval **O**rdnance **L**aboratory). That same year he made an observation about [NITINOL] that hinted at the extraordinary, but still undiscovered, property of Nitinol.

> I distinctly remember my very exciting discovery of the acoustic damping change with temperature change near room temperature. This unusual event unfolded when my…assistant…and I were melting a number of [Nitinol] bars in the arc-melting furnace. On the day in question (circa 1959), six arc-cast bars were made. While cooling on the…table, the first bars arc-cast into bar form had cooled to near room temperature, while the last bars to be cast were still too hot…to be handled with bare hands. Between the cool (first bar) and the very warm bar (last bar) were four…bars possessing a broad spectrum of temperatures…My "hands-on" approach caused me to take the cooler bars to the shop grinder to manually grind away any surface irregularities that might produce a subsequent scaly or bad….surface. In going from the table to the bench grinder, I purposely dropped the cool (near room temperature) bar on the concrete laboratory floor [a quick test to determine roughly the damping capacity of an alloy]. It produced a very dull "thud," very much like what one would expect from a similar size and shape lead bar.
>
> My immediate concern was that the arc-casting process may have in some way produced a multitude of micro cracks within the bar—thus producing the unexpected damping phenomena. With this possibly discouraging development in mind, I decided to drop the others on the concrete floor. To my amazement, the warmer bars rang with bell-like quality.
>
> Following this I literally ran with one of the warmer bars (that rang) to the closest source of cold water—the drinking fountain—and chilled the warm bar. After thorough cooling the bar was again dropped on the floor. To my continued amazement it now exhibited the leaden-like acoustic response. To confirm this unique change, the cooled bars were heated through in boiling water—they now rang brilliantly when dropped upon the concrete floor.

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> Subsequent discussions with my melter assistant revealed that he had in no way mixed or altered the alloy compositions during repeated melting. This immediately alerted me to the fact that the marked acoustic damping change was related to a major atomic structural change, related only to minor temperature variation.
>
> Following the startling acoustic damping discovery, other seemingly related unique changes were observed. More interestingly, these changes also occurred in about the same temperature range as the acoustic damping change.[1]

In the early 1960s Buehler prepared a long, thin (0.010-inch thick) strip of Nitinol to use in demonstrations of the material's unique fatigue-resistant properties. He bent the strip into short folds longitudinally, forming a sort of metallic accordion. The strip was then compressed and stretched (as an accordion) repeatedly and rapidly at room temperature without breaking. In 1961 a laboratory management meeting was scheduled to review ongoing projects. Unable to attend, Buehler sent… his assistant to the meeting to present [their] work. As one of their "props" for the review, [the assistant] took the accordion folded fatigue-resistant strip. During the presentation, it was passed around the conference table and flexed repeatedly by all present. One of the Associate Technical Directors, Dr. David S. Muzzey, who was a pipe smoker, applied heat from his pipe lighter to the compressed strip. To everyone's amazement, the Nitinol stretched out longitudinally. The mechanical memory discovery, while not made in Buehler's metallurgical laboratory, was the missing piece of the puzzle… [and] became the ultimate payoff for Nitinol.

In 1962 Dr. Frederick E. Wang joined Buehler's group at the Naval Ordnance Laboratory, his expertise in crystal physics being vitally needed. Wang, born on August 1, 1932 in Su-Tou, Formosa (now Taiwan), emigrated to the United States and did his undergraduate work in chemistry and physics at the University of Tennessee at Knoxville. After receiving his doctorate in physical chemistry from Syracuse University in 1960, he worked as a postdoctoral associate for future (1976) Nobel chemistry laureate William Nunn Lipscomb, Jr. at Harvard University, until he left to join Buehler at NOL. The commercial applications of Nitinol that were to come would not have been possible without Wang's discovery of how the shape memory property of Nitinol works.

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