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Clearing the Way: A Design Project

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Description:
This project is intended to expose students to the field of biomedical engineering (bioengineering) through the design and testing of solutions for clearing arteries blocked by atherosclerosis.

Prerequisites:
Ability to take an average of three numbers
Basic knowledge of human systems (recommended but not necessary)

Instruction Time:
120 minutes

Audience:
Middle school science students

Lesson Objective:
Students will be able to describe what happens when an artery gets blocked and apply the engineering design cycle to create a solution.

Next Generation Science Standards Addressed:
MS-ETS1-1
MS-ETS1-2
MS-ETS1-3
MS-ETS1-4

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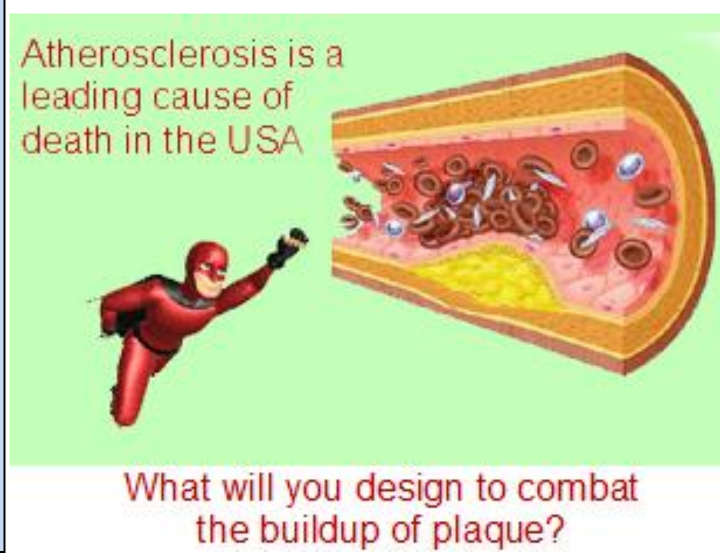


Lesson Overview:

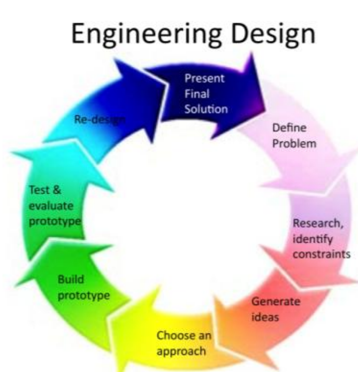
This project is intended to expose students to the field of biomedical engineering (bioengineering) through the design and testing of solutions for clearing arteries blocked by atherosclerosis. Students will be given an overview of the field of biomedical engineering and an introduction to the cardiovascular system. They will play the role of biomedical engineers tasked with coming up with a design for opening up a blocked artery using a model system. Through this project, students will be presented with a problem and the design criteria that must be met in order to fix it (both key components of the 'engineering design cycle'). Further, students will tackle the remainder of the engineering design cycle by brainstorming solutions, choosing an approach, building and implementing their design, testing its success, and proposing redesign options.

Background Information:

It might be helpful for teachers to know the following information about the circulatory system. The circulatory system is responsible for transporting blood throughout the human body. Blood delivers oxygen and other nutrients to the body's cells but also works to clear the body of waste and toxins. The heart serves as a pump for the blood, pushing it through blood vessels called arteries. The arteries carry the blood away from the heart and into smaller blood vessels called capillaries. It is in the capillaries that the blood exchanges nutrients and oxygen for waste and carbon dioxide. The blood returns to the heart through veins, another kind of blood vessel.

Biomedical engineers work with doctors and other engineers to design solutions to problems within the circulatory system. One such problem is atherosclerosis, the hardening of artery walls due to the accumulation of fatty deposits (plaque) within the arteries. This causes a narrowing of the arteries that can lead to a heart attack or stroke unless blood flow can be restored. There are two major ways that surgeons try to open up arteries: (1) angioplasty combined with stenting and (2) coronary bypass (for the heart). Angioplasty involves threading a wire (usually starting in a large artery in the leg) to the spot of the blockage. The wire contains a balloon that can be filled with a salt solution to expand the walls of the artery. Sometimes this is done alone but other times doctors add a stent (a wire mesh-like tube, can be drug coated) to keep the artery open and blood flowing to its destination. In severe or complicated cases, doctors may perform a coronary bypass (e.g. double/triple/quadruple bypass) which uses a patient's own arteries or artificial polymer arteries to make a pipeline around the blockage in the artery of interest. There are also pharmaceutical drug products that attempt to prevent and decrease the buildup of plaque. Doctors do not try to remove the plaque from the arteries. This is because the plaque is within the walls of the arteries and difficult to access and, even if the plaque was accessible, it could get knocked off and cause problems elsewhere, blocking other, smaller arteries.

Biomedical engineers use models extensively in research and design. This is because they cannot work on their system (the human body) without risking harm to a person. The engineering design cycle is a simplified recipe for how engineers address their problems of interest. It is shown to the right.



Learning Objectives & Assessment:

Students will be able to…	Assessment
...list the two factors that contribute to plaque buildup and describe the risks of having a blocked artery.	Think-pair-share white board activity, discussion, responses on handout #3
...measure and document the differences between a clear and blocked artery (model system).	Completion of demo question on handout #2
...brainstorm and describe/draw a plan for restoring "blood flow" to an artery using a given set of materials.	Completion of group planning question on handout #2
...create and implement their design.	Check if groups have a final design prototype for testing
…critically assess the designs of their peers and make suggestions for improvement.	Completion of peer evaluation (handout #5)
...share their design with the class and justify its components.	Discussion and class presentation
...assess the performance of their design using a design criteria checklist.	Completion of group self-evaluation (handout #4)
...generate plans for redesign.	Completion of group brainstorming on handout #4, discussion

Alignment to Next Generation Science Standards:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

This lesson has also been designed to align with the NRC Framework for students enrolled in middle school through grade 8.

Disciplinary core ideas
ETS 1: Engineering Design
ETS 1.A: Defining and delimiting an engineering problem

This lesson outlines the problems associated with the circulatory system. It provides the design criteria and determinants of success as an example of managing an engineering problem.

ETS 1.B: Developing possible solutions

This lesson provides the opportunity for students to build and test their artery solutions. They also share their designs and do re-design sketches. All this is with the use of models.

Crosscutting concepts
4. Systems and System Models

"Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.
-Models are limited in that they only represent certain aspects of the system under study." – NRC Framework

This lesson is based entirely on models. It includes discussion on why engineers use models but also their disadvantages.

Science and engineering practices
Planning and Carrying Out Investigations
"*Collect data about the performance of a proposed object, tool, or system under a range of conditions." – NRC Framework*

This lesson includes testing of the artery unblocking solutions. Water was poured through in triplicate and time that this took was measured.

Vocabulary:

Biomedical engineering (bioengineering)- combination of medicine and engineering; based on the search for solutions to health problems

Circulatory system- a major part of the human body responsible for moving blood throughout it; transports nutrients and oxygen to cells and removes waste and carbon dioxide; system is made up of arteries, veins, capillaries and the heart

Blood vessels- tubes that carry blood throughout the body

Heart- four chambered pump that is responsible for moving blood to the lungs to be oxygenated and then throughout the body

Arteries- type of blood vessels that carry blood (full of oxygen and nutrients) away from the heart into the limbs and other organs

Veins- type of blood vessels that carry blood (containing waste and carbon dioxide) back to the lungs and heart for exchange

Capillaries- narrow connections between arteries and veins where exchange occurs

Atherosclerosis- thickening and hardening of arteries due to plaque buildup in arterial walls

Plaque- accumulation of lipids (cholesterol and fatty acids), cells, debris, and calcium in arterial walls which causes swelling and hardening of the artery walls; commonly referred to as a blood clot (although this is not technically correct); blood clots can subsequently form on the protruding arterial walls

Heart attack- interruption of blood supply to the heart most commonly due to a blockage of the coronary (heart) arteries; can cause damage to the heart tissue and/or death

Stroke- loss of brain function due to disturbance in the blood supply; this can be due to a blockage or extensive bleeding (hemorrhage); can result in loss of the ability to move, speak, and see as well as death; a stroke is not to be confused with a seizure which is caused by the misfiring of brain neurons (nerve cells)

Materials:

<table>
<tr><th>Paper Resources</th><th>Technology & Multimedia Resources</th><th>Physical Resources</th></tr>
<tr><td>Handout #1: Anticipation Guide (1 per student)</td><td>Computer with projector</td><td rowspan="2">For demonstration and/or testing: clear artery, blocked artery, bucket, tray, stop watch, 2 half gallon jugs filled with water (dye with red food coloring for blood-like effect)</td></tr>
<tr><td>Handout #2: Brainstorming Activity (1 per group)</td><td>Access to PowerPoint</td></tr>
<tr><td>Handout #3: Circulatory System Review (1 per student)</td><td>Linked video is available on YouTube but is provided as a download that is compatible with Windows Media Player and iTunes</td><td rowspan="3">For design supply kits (1 per group): 2- 6 inch pieces of clear PVC vinyl tubing (found in the plumbing section of Lowes, sold by the foot for approx. $2); Play-Doh (1 regular sized tub can clog approx. 4 tubes); 6 inches off a roll of aluminum foil; 5 drinking straws; 4 pipe cleaners; 10 paper clips; 3 rubber bands; 10 toothpicks; 5 cotton balls; 1 small basic sponge (no scrubbing pad needed, can be cut from large sponge); 2 feet of twine; 10 small craft sticks (popsicle sticks that are approx. 3 inches in length). All values are approximate and can be adjusted on a class-by-class basis.</td></tr>
<tr><td>Handout #4: Design Self Evaluation (1 per group)</td><td>Scientific calculators (1 per group)</td></tr>
<tr><td>Handout #5: Design Peer Evaluation (1 per student)</td><td></td></tr>
<tr><td></td><td></td><td>For general class use during building: scissors, balloon pumps (can be found in party supply stores); recommend only 2-3 pumps per class because they can be a distraction and although the balloons are a popular strategy, they are not the most efficient; limiting the pumps can drive the students to look for better design solutions.</td></tr>
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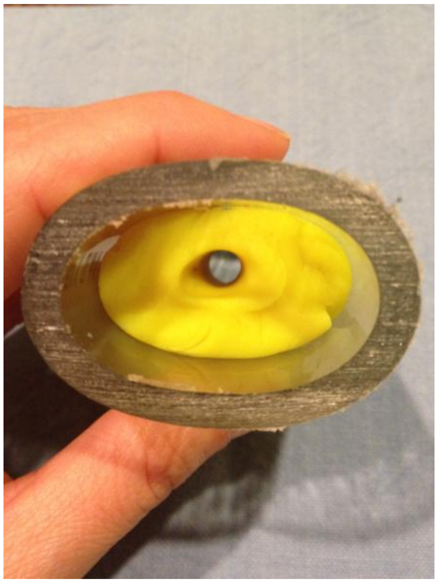
Lesson plan:

Before class:

1. Cut tubing (PVC clear vinyl, 1.25 inch inner diameter) for clear and blocked arteries. It is recommended that the tubing is cut to approximately 6 inches in length. Most clear plumbing tubing can be cut with a box knife, X-ACTO knife or similar sharp instrument. This lesson requires one (1) clear and one (1) blocked "artery" for the demonstration and then one (1) blocked artery per group. If the lesson involves redesign, two (2) blocked arteries per group are recommended. It is expected that the tubing can be cleaned out and reused for other lessons at a later date.

2. Create blocked artery. Take a 1 inch ball of Play-Doh and center it in the middle of the length of the clear tubing. Push it up against the sides of the tubing to remove any air pockets. Use a pencil to create a hole all the way through the Play-Doh. The hole doesn't have to be much wider than the pencil. See pictures below. To avoid having the Play-Doh dry out, do this as close as possible to the time these are going to be used by the students. If the blocked arteries need to be saved between classes, it is recommended that they are stored in small Ziploc bags to avoid having the Play-Doh dry out. In lieu of Play-Doh, oil based modeling clay can also be used. It responds better to water and will not dry out like Play-Doh. However, it is tougher to work with during the design project. Using the balloons and a balloon pump will not open the artery if it is clogged with clay but other techniques can still be successful.



For class time:

The handouts provided were developed for a series of 3- 40 minute classes. Based on this, recommended start/stop times have been noted. Adjustments may need to be made for shorter/longer class periods and for other specific classroom needs.

Pass out Handout #1 (one per student) with circulatory system knowledge survey.

1. Have students fill out 'before' portion of the 'before/after you learn" anticipation guide on the circulatory system and reflect on their knowledge (Question 2). (Time required: 5 mins, *Pre*-**EVALUATION**)

2. Give introduction to bioengineering using supplemental PowerPoint presentation. (Time required: 5 mins, **ENGAGE**)
    a. What is biomedical engineering? (Slide 3)
        i. Combination of engineering and medicine
        ii. Search for solutions to health problems
    b. What might a bioengineer build? Examples are listed below. This could be introduced as interactive questions. (Slide 3)
        i. Has anyone broken a bone? –Biomedical engineers have a role in designing x-ray equipment.
        ii. Do any of you have a grandparent or parent who needed a hip or knee replacement? –Biomedical engineers work on designing, improving, and testing these implants.
        iii. Do any of you have younger brothers/sisters or cousins? Have you ever seen an ultrasound of a baby? –Biomedical engineers help develop ultrasound techniques and equipment.
        iv. Other examples: Prosthetic limbs, artificial organs, materials for knee (ACL etc) repair, machines for hospitals (MRI, IV pumps, etc), dental fillings/crowns, absorbable stitches, tissue engineered skin, bladders or blood vessels, stents, etc.
    c. Who might bioengineers work with? (Slide 4)
        i. Electrical engineers, materials scientists, mechanical engineers, chemical engineers

3. Give presentation (continuing in PowerPoint) on circulatory system with following discussion questions for the students (*anticipated responses*), use think-pair-share white board technique. (Time required: 10 mins, **EXPLAIN**)
    a. One thing that a biomedical engineer might study is the circulatory system; does anyone know what that is? (Slide 5)
        i. *System that pumps blood through your body*
        ii. *Transports nutrients and oxygen throughout the body*
        iii. *Made up of arteries, veins, capillaries, heart*

   b. Have you ever heard of someone having a blocked artery? What did that mean? Why does it happen? (Slide 6)
      i. *Blockage is made up of fat. It causes the artery walls to get thicker and harder. Risk factors are poor diet, a lack of exercise, and smoking. Although just because you eat right and exercise, doesn't mean you aren't at risk (genetics plays a role too).*
   c. What problems might result from a clogged artery? (Slide 7)
      i. *Heart attack (if this happens in cardiac arteries), stroke (if this happens in brain)*

4. Demonstrate flow through clear and blocked arteries by pouring one half gallon of water through the tube into a bucket. See the Appendix for set up suggestions. Explain the use of models for studying systems in bioengineering. (Time required: 5 mins, **EXPLORE**)
   a. Before the demonstration starts, have the students guess how long it will take for all the water to go through each tube.
   b. Get 1 student volunteer per artery to time with a stopwatch how long it takes for the water to get through the artery.
   c. Record the actual time it takes for half a gallon of water to pass through each tube.
   d. Explain that a lot of engineers use models but biomedical engineers in particular need to use models because they work with products for the human body. It would dangerous for engineers to work directly on humans before they fully understand their design and its limitations. Biomedical engineers first work with laboratory models and simulations; using isolated cells or other conditions to test their products' efficacy. Then tests are done on animals of increasing size and complexity (i.e. mice, rabbits, sheep…) before clinical trials on humans are allowed to begin.

5. Give bioengineering design criteria from Slide 9. (Time required: 2 mins, **EXPLAIN**)
   a. Students are engineers at Flow Right, INC. I have come to you with this problem, how are you going to fix it?
   b. This is what I want out of your <u>product</u>:
      i. Must improve blood flow through the artery
      ii. Must NOT cause plaque to get knocked off and float downstream
      iii. Must create a product with the materials given
   c. Describe/show the materials available to them: rubber bands, aluminum foil, long balloons, regular balloons, balloon pumps, packing tape, paper clips, toothpicks, craft sticks, cotton balls, etc. (Slide 10)

Pass out Handout #2 (one per group) and have the students fill out the times from the demonstration and read the design criteria again in their groups.

6. Allow time for brainstorm/planning (Time required: 15 minutes, **EXPLORE**)
   a. Have the students draw their plan (one per group). It should be detailed and labeled.
   b. When working with each group, reinforce the idea of creating a device (rather than a technique) that can be sold to a hospital for use by their surgeons.

7. Review (Time required: 3 mins, **EVALUATE**)
   a. Have students fill out after portion of 'before/after you learn" anticipation guide on the circulatory system and reflection question (Question 3). Collect the anticipation guide and review the data to guide instructions/review time for the next day.

Recommended end of Day 1, start of Day 2.
Pass out Handout #3 and have students complete it.

8. Have the students complete the circulatory system review (Handout #3) once you've processed to the next day or an extended period of time has passed. Go over their answers.(Time required: 5 mins, **ENGAGE**)
   a. Reinforce: What problem are you trying to solve? What are the causes of this problem?

9. Discuss the elements of the engineering design cycle: PowerPoint slides 15 & 16. (Time required: 5 mins, **EXPLAIN**)
   a. Go through the engineering design cycle and discuss how each part of the lesson aligns with it.
   b. What are the design requirements? (Put them on the board.)

Ask students to take out their brainstorming sheets.

10. Address lab safety rules/expectations for group behavior. (Time required: 2 mins)
    a. There is very little in the design kits that have the potential to pose harm to the students (only sharp ends on paper clips and toothpicks). However, it will be useful to address the proper use of the balloons and balloon pumps. Limiting the use of the pumps to those students who are using them productively for their designs will deter students from using them for fun and for trying to pop the balloons.

11. Allow the students to build their artery solutions (Time required: 25 mins, **EXPLORE**)
    a. Have the students review their design plans.
    b. Challenge the students to gather their materials and implement their design.

12. Review (Time required: 2 mins)
    a. Remind students that they have completed about half of the engineering design cycle: defined problem, identify constraints, generate ideas, choose approach, and build prototype. Next, they will test and evaluate the prototypes and discuss options for redesign.

13. Recommended clean-up and prototype storage, if required. (Time required: 2 mins)
    a. Have the students put all of their materials, their prototype, and their worksheets in a single gallon sized Ziploc bag for easy collection and distribution for testing.

Recommended end of Day 2, start of Day 3.
Pass out prototypes for testing.

14. Taking the next step in the engineering design cycle: testing!
    (Time required: 5 mins, **ENGAGE**)
    a. Explain how testing will work.
    b. Set up leader board for testing times. (Example on Slide 22.)

15. Have students share their designs and test them in front of the whole class
    (Time required: 5 mins per group, **EXPLORE**)
    a. Each group should come to the front of the class to explain their design approach (what they did) and try to "sell" it to their classmates.
    b. Test the designs in triplicate (or once to cut down on time) and have the students average their times.
    c. While each group is testing, have the remaining groups fill out their peer evaluation forms. Do one as an example to guide the class and set expectations for critical thinking. (Template on Slide 21.)

16. Have the students self-evaluate their design performance.
    (Time required: 5 mins, **EVALUATE**)
    a. Fill out the testing rubric and answer questions 3. (Questions 4 & 5 are questions for optional extension activities.)

17. Explain how arteries are cleared in real life by showing a video.
    (Time required: 5 mins, **EXPLAIN**)
    a. Highly recommend "Angioplasty 1" video in "Additional Information"
        i. Best presented on mute with the teacher narrating and controlling the pace of the video.

18. Closing: Are your designs like those in the video? Did you come up with something completely different? The last step of the engineering design cycle is redesign. What would you change for next time and why?
    (Time required: 5 mins, **ELABORATE/EVALUATE**)

Optional extension activity #1: What are some challenges that design engineers might have to face that you did not have to worry about? (Question 5 on Handout #4.)

1. *Engineers can't see/hold the artery like you are*
2. *Blood is always flowing through the artery*
3. *You don't want the person to bleed too much, losing too much blood is a bad thing*
4. *You don't want to puncture the walls of the arteries, in real life they are softer, more elastic*

Optional extension activity #2: Allow the students time to redesign their artery opening solutions using the parts of their or their classmates' designs that worked and eliminating the parts that didn't work. Retest to see if they improved their times.

Additional Information and Links:

Information about biomedical engineering:

- Biomedical engineering society: http://bmes.org/content.asp?contentid=40
- One of the Best Jobs in America (CNN Money): http://money.cnn.com/pf/best-jobs/2012/snapshots/index.html

Examples of things biomedical engineers make:

- Artificial Heart: http://science.howstuffworks.com/innovation/everyday-innovations/artificial-heart.htm
- MRI: http://www.howstuffworks.com/mri.htm

Information about the circulatory system:

- Kids Health from Nemours: http://kidshealth.org/parent/general/body_basics/heart.html
- neoK12 (Circulatory quizzes and videos): http://www.neok12.com/Circulatory-System.htm
- Texas Heart Institute- Heart Info Center: http://www.texasheartinstitute.org/HIC/Anatomy/

Information about plaque buildup and its treatment:

- Guide to Cardiologists: http://www.consumersresearchcncl.org/Healthcare/Cardiologists/cardio_chapters.html
- NIH Coronary Artery Disease: http://www.nhlbi.nih.gov/health/health-topics/topics/cad/
- Stokes: http://www.strokegenomics.org/index.php?page=about-stroke-genetics

Videos (highly recommend "Angioplasty 1"):

- Bioengineering: http://www.sciencelearn.org.nz/Science-Stories/Science-Made-Simple/Sci-Media/Video/Bioengineering
- Angioplasty 1: https://www.youtube.com/watch?v=S9AqBd4RExk
- Angioplasty 2: https://www.youtube.com/watch?v=9FPapBbbS4o

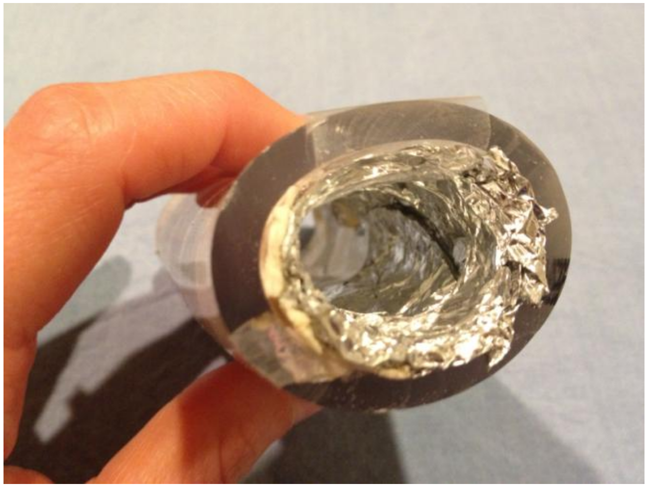
Appendix:

Recommended demo and testing setup:

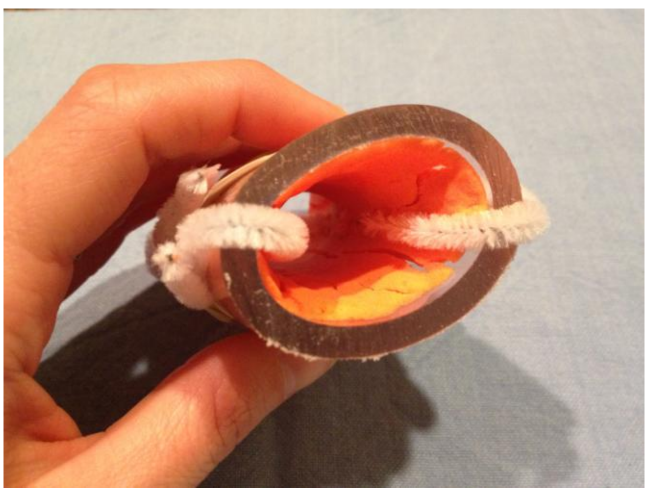
By placing the collection bucket for flow through in a tray, the mess of spills and splashes can be minimized. The artery can be manually held in place or taped in the spout of the bucket using packing tape as shown here. Pour as steadily and consistently as possible for all designs. Using a funnel is also something to consider if the appropriate size/fit can be found. I also recommend that a bucket with a narrow spout is used if the water is planning on being reused across several groups. This makes pouring that water back into the half gallon jug much easier.

Students may ask how they can be sure that it is a fair competition if the pouring isn't standardized. I would recommend having the teacher pour for all conditions to assure as constant flow as possible. This eliminates some variation between groups but isn't perfect. In any case, this may be a good time to discuss how engineers have to be very careful about testing just one variable at a time and that in real life, the flow would be produced by a machine in order to be as precise and consistent as possible.

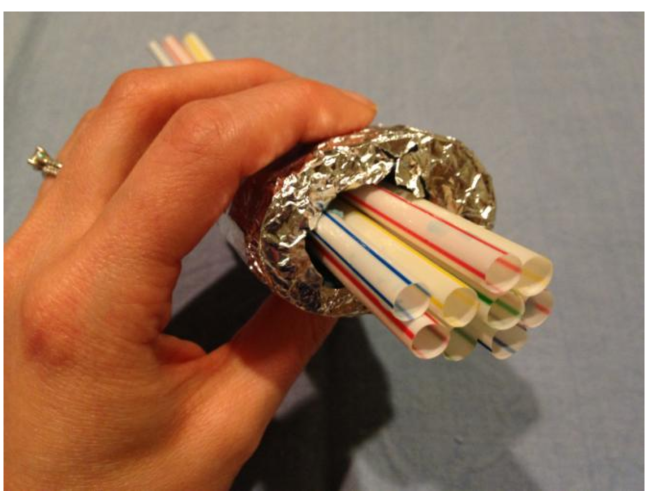
Examples of student-designed solutions:



Many students chose to open their arteries using craft sticks or similar instruments and then fill the artery with foil to prevent any of the plaque from being knocked off during testing. This group chose to secure its foil with tape. Other groups built a tape “trap” that would catch any plaque that may have gotten past the foil lining.



This group opened their artery with pipe cleaners and then secured them to the outside of the artery with rubber bands. They reasoned that the pipe cleaners could be reused if the plaque was to build up again.



This group decided to open their blockage with straws and then leave them to guide the blood beyond the blockage. They finished their design off with a plaque trap of foil. While creative, this is not a design I would recommend because it did not perform any better than the blocked artery from the demonstration.