**Heart Valve PBL**

**Grade Level:** 7 **Subject:** Integrated Science

**Authors:** Ellen Smith (Einstein Middle School, Shoreline),

Briahna Attebery (Einstein Middle, Shoreline, School),

Tamara Haberlack (Hidden River Middle School, Monroe),

Christopher Skilton (health and environmental investigator, King County Public Health),

Eric Lagally (science instructor, Western Governors University),

Mariola Kulawiec (curriculum developer, Witty Scientists)

**Problem Statement:**

11-year-old Felipe is crazy for soccer. For as long as Seattle FC has been playing, he has been their number one fan. He was kicking a ball from the time he could walk. In the last two years, though, he has not been able to keep up with his team. He gets tired too quickly and is always out of breath. When his mother took him to the doctor, they learned that his heart was not like other hearts. One of his heart valves was not working properly. It turns out that his condition is a rare genetic disorder and also affects his 4-year-old sister. The only thing he loves more than soccer is his baby sister. He is broken-hearted in more ways than one. Your goal is to design an artificial heart valve that could help Felipe. To be successful, your model heart valve must allow 100% of the blood to flow through in one direction and prevent blood from flowing through in the reverse direction.

**Conceptual Storyline:**

During this unit students will design, construct and test a model heart valve using the steps of the engineering design process as outlined below:

1. **Identify the Problem:** Students will identify the problem, including criteria and constraints. When creating an model heart valve, students will consider durability, effectiveness, cost, materials and time.
2. **Gather Information:** Students will learn about the function of heart valves and see a variety of one-way valve designs.
3. **Develop a Plan:** Students will work within a budget to design a model heart valve.
4. **Build and Test:** Students will build and test their model heart valve. Students will collect data on their model heart valve and use their data to evaluate its effectiveness.
5. **Redesign:** Students will modify their original design while continuing to work within a budget.
6. **Build and Test Again:** Students will build and test their redesigned model heart valve. Students will collect data on their model heart valve and use their data to evaluate its effectiveness.
7. **Reflect:** Students will reflect on using the engineering design process to solve a problem. Students will consider the variety of careers that are part of the engineering design process.

Prior to this unit students should have:

* An understanding of the concepts in MS-LS1-3 (*Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells)* with an emphasis on how a problem in the cardiovascular system can affect other systems in the human body.
* A basic understanding of how blood flows in one direction through the heart via one-way valves.

**Standards (NGSS, CCSS, CTE):**

NGSS 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.

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

NGSS 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.

NGSS 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.

**21st Century Skills:**

Collaboration, Creativity, Communication, Problem-Solving, Critical Thinking, Enthusiasm

**Locally and/or Personally Relevant for Students:**

Students may have someone in their family that has needed a heart valve replacement or that has benefited from some other type of medical technology.

**Connections to career and educational pathways:**

On the last day of the unit, students will complete a reflection of the design process. As part of this lesson, students will discuss the various careers that would be involved in designing, producing, marking and implementing an artificial heart valve.

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**Teacher Preparation and Materials**

**Materials needed for the unit:**

* **Student work packet:** All of the handouts are included in a single student packet.
* **Presentation Materials:** There are 2 PowerPoint presentations (Felipe’s Story and Introduction to the Heart Valve) that you may wish to use with this unit.
* **Building materials:** A variety of items including paper, paperclips, string, tape and plastic bags that students can use to build their heart valve models. See the student packet for a more detailed list of building materials.
* **Blood simulant:** Red glass beads work well, but you could potentially use a variety of items. We found that 400 – 500 mL of “blood” per testing apparatus worked well, but you could use a variety of volumes depending on your available materials.
* **Testing Apparatus:** Before beginning this unit, you will need to build the testing apparatus, which is essentially a tube in which students will attach their model heart valves and through which students will pour “blood.” Pictures and detailed instructions of how to build the testing apparatus can be found at the link below. We found that it was ideal to have 4 – 6 testing apparatus for a classroom of up to 32 students, with students working in groups of 2 – 4.

**Testing Apparatus Building Instructions:**

http://www.instructables.com/id/Middle-School-heart-valve-model-testing-apparatus/

**Budget for Testing Apparatus:**

**For 6 test setups (not including tax or shipping):**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *With PVC couplings:* |  |  |  |  |  |
| **Item** | **Supplier** | **Part #** | **Unit Price** | **# required** | **Subtotal** |
| 3" coupling (PVC) | Home Depot | 189030 | $1.37 | 6 | $8.22 |
| 3.5" OD washer | Fastenal | 33514 | $1.90 | 6 | $11.40 |
| 3.5" OD acrylic pipe (6 foot length) | US Plastics | 44544 | $44.70 | 1 | $44.70 |
|  |  |  |  |  |  |
|  |  |  |  | **Total:** | **$64.32** |
| *With ABS couplings:* |  |  |  |  |  |
| 3" coupling (ABS) | Home Depot | 188255 | $1.83 | 6 | $10.98 |
| 3.5" OD washer | Fastenal | 33514 | $1.90 | 6 | $11.40 |
| 3.5" OD acrylic pipe | US Plastics | 44544 | $44.70 | 1 | $44.70 |
|  |  |  |  |  |  |
|  |  |  |  | **Total:** | **$67.08** |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

**Lesson Plan #1: Introduction to the Problem (Day 1)**

**Problem Statement**: Can we design a model heart valve that maximizes the forward flow of “blood” through it while minimizing the back flow of “blood,” and that is robust enough to allow for repeated use?

**Learning objectives:**

1. Students will understand the steps to the Engineering Design Process.
2. Students will identify the criteria and constraints that frame the challenge in this Engineering Design Process.
3. Students will draw and label a diagram of a one-way valve as well as list characteristics a one-way valve needs to work well.

**Materials:**

* Heart Valve Project Student Packet
* Highlighters and/or colored pencils
* Felipe’s Story Power Point
* Introduction to Heart Valves Power Point

**Lesson Preparation:** Make copies of the student work packet.

**Time required:** One 50-minute class period

**Lesson Procedure:**

*Introduction: Problem Launch*

1. Select one of the options described below to introduce the problem:
2. Option One for Setting the Problem: Read the storyline about Felipe. Use either the Felipe’s Story PowerPoint or Introduction to Heart Valves PowerPoint.
3. Option Two for Setting the Problem: Use the Introduction to Heart Valves PowerPoint. Go to Slide 7. Show the embedded video clip ‘John Q.’ Don’t give an introduction. Instruct students to watch but not comment, yet. After the video clip pose the follow questions:
   * What are possible explanations for the boy collapsing?
   * Why am I showing you this?
   * This is an example of traumatic heart failure. What are symptoms of heart problems that are less dramatic? How can a poorly functioning heart affect overall health?

*Main class activity: Define the Problem, Gather Information*

1. Pass out the student work packet.
2. Give an overview of the steps in the Engineering Design Process that we will follow. (Introduction to Heart Valves Power Point)
3. Go over the expectations of working together as a group and the requirement that a signature or stamp is needed once everyone has completed a step before a group can proceed to the next step.
4. Discuss the meaning of the words *criteria* (requirements) and *constraints* (limitations).
5. Read the problem statement out loud and identify criteria and constraints. Highlight the criteria in one color and the constraints in another.
6. Show Keynote on one-way valves. Direct students to Step 2: Gathering Information. Use images of different types of one-way valves from Power Point.
7. Students sketch, label and explain how a one-way valve works.
8. Students work in small groups to list important characteristics of a one-way valve.
9. Utilize additional slides in Introduction to Heart Valves Power Point to review information about how blood flows through the heart.
10. Discuss how a functioning heart valve must meet the criteria identified in Step 1 of student packet.

*Conclusion:* Review Felipe’s Story or the John Q. clip. Give an overview of Step 3: Developing a Plan.

**Assessment:** Most of today’s work was done with teacher direction. While students are working on Step 2 of the student packet, spend time with each group. Stamp or sign Steps 1 and 2 on the front page of the packet, as needed. If students haven’t finished Step 1 or 2 in the packet assign it as homework.

**Accommodations:** Students will work in groups of 2 - 4. Careful choice of group members may be required for proper accommodations. Students with differing physical abilities may not be able to participate in valve construction but can assist with valve design and testing, depending on their physical ability. Students with social limitations may work on individual valve design and testing as appropriate.

**Extensions:** Students who thoroughly complete Steps 1 and 2 can read the rest of the Steps in the packet. Discussion about planning can begin.

**Lesson #2: Design & Build (Day 2-4)**

**Problem Statement**: Can we design a model heart valve that maximizes the forward flow of “blood” through it while minimizing the back flow of “blood,” and that is robust enough to allow for repeated use?

**Learning objectives:**

* + 1. Students will design a model heart valve using simple materials that maximizes forward flow of the blood simulant, red glass beads, through a testing apparatus.
    2. Students will measure the flow of the blood simulant, red glass beads, through their model heart valve.
    3. Students will modify the initial design of the heart valve to optimize forward flow, minimize back flow, and maximize durability.

**Materials:**

* Model heart valve testing apparatus (sufficient number to allow streamlined testing of students' model valves, usually 1 per 5-6 students).
* Optional: Metal washers that match the inner diameter of the testing apparatus - these can be used to define the size of students' model valves.
* Model heart valve materials according to student packet, including:
  + Paper clips
  + Cardstock
  + Rubber bands
  + String
  + Masking tape
  + Large and small plastic bags
  + Paper
* Graduated plastic beakers (2 per testing apparatus). Students will use these to measure the volume of forward flow and back flow.
* Red glass beads as blood simulant (400 - 1000 mL per testing apparatus)

**Lesson Preparation:** Ensure students have the student work packet

Optional: issue scrip for student groups to purchase valve materials

**Time required:** Three 50-minute class periods

**Procedure:**

*Introduction:* You may choose to begin each day of this portion of the unit with an entry question. Suggested entry questions are listed below. For each entry question, you could have student write their responses silently, then discuss with partners or as a whole group.

* Day Two entry question: “How does a faulty heart valve affect other systems of the body?” Example systems: Digestive, skeletal, muscular and respiratory.
* Day Three entry question: "What material would work the best for your heart valve?" Explain.
* Day Four entry question: “In creating your design for the heart valve, what were the factors that influenced your decision?” Explain.

*Main class activity: Generate Possible Solutions & Determine Best Fit Solution*

1. Students break into groups of 3-4 students and begin design of valves. Students discuss best materials to use and reflect on others' answers to the entry question. Teacher circulates to answer student questions and to observe for student reflection of entry question.
2. Students draw out and label their first design in the student work packet and present their design idea with cost list for materials (student work packet Step 3). Teacher approves the first design.
3. Students build model valves using their first designs.
4. Students test flow of red glass beads through model valves using the test apparatus and plastic beakers. Students measure forward flow by measuring the volume of beads that successfully pass through the valve in the forward direction. Students record their data in the student packet. Students then flip the test apparatus and test back flow of glass beads through the test apparatus in the opposite direction. Students complete multiple trials (3- 5 trials work well) and gauge the durability of their valves based on the number of trials their valve survives.
5. Students complete Step 4 of the student work packet.
6. Students will redesign and label their heart valve, highlighting changes made to the original design (student work packet page 5).
7. Students will create a new cost list for the materials needed for the redesign.
8. Students will repeat the testing, data collection, and heart model evaluation process (steps 4 and 5 above) for their redesigned heart valve.
9. When students have completed testing their redesigned heart valve model, they should turn in their model heart valve along with a copy of their data table showing the data they collected for the model. You could have preprinted data tables ready for them or you could have them recreate the data table on an index card. You may want them to include additional information on the card, such as the cost of the model or a sketch of their design. Their heart valve models and data tables will be posted around the room for a gallery walk at the end of the unit.

To facilitate group work, you may wish to have a list of **conversation starters** posted on your board while students are working:

1. I noticed that…..
2. What materials do you think we should use?
3. Why did you choose to put…..in your design?
4. Tell me about….
5. If we could change one part of our design, what would you suggest?

To facilitate student reflection on their design, you could use some of these questions while you are checking in with each group:

1. What did you observe or notice about the blood flow?
2. Why do you think that happens?
3. What could you do differently to make your design more effective?
4. How would the changes you plan to make affect your blood flow?

*Conclusion:* At the end of each class period, student teams should take a few minutes to reflect on their designs and create a plan for the next day’s work.

**Assessment:** Teacher approves initial design concepts and valve costs according to the student work packet on a per-group basis. Teacher also observes student groups for soft skills including collaboration and critical thinking about valve materials.

**Accommodations:** Students will work in groups, and careful choice of group members may be required for proper accommodations. Students with differing physical abilities may not be able to participate in valve construction but can assist with valve design and testing, depending on their physical ability. Students with social limitations may work on individual valve design and testing as appropriate.

**Extensions:** Students who achieve 100% forward flow and no back flow in their initial design and test cycle can begin to optimize other features of valve performance. For example, repeated testing for durability may reveal faults that appear over time. The teacher may also provide additional design challenges for the students based on actual heart geometry (“this valve needs to have two/three flaps - can you design one like that?”). Students with a successful valve design could now problem solve how to build an effective valve that has a lower cost.

**Lesson #3: Reflection (Day 5)**

**Problem Statement**: Can we design a model heart valve that maximizes the forward flow of “blood” through it while minimizing the back flow of “blood,” and that is robust enough to allow for repeated use?

**Learning objectives:**

1. Students will reflect on the engineering design process and their contribution to it.
2. Students will describe a variety of careers that are involved in the engineering design process.
3. Students will describe the impact of a faulty heart valve on a person, including describing the way that body systems interact with each other.

**Materials:**

* Completed valves with data tables that show the amount of blood flow and backflow.
* Student work packet.

**Lesson Preparation:**

Arrange students’ heart valve models with data tables around the classroom so that they will be easily visible to students during a gallery walk. You may wish to highlight data tables for heart valve models that met all criteria so that students can easily see which heart valve models were successful.

**Time required:**  50-minute class period

**Procedure:**

*Introduction: Gallery Walk*: *Present Solutions & Debrief the Problem*

1. Ask students to silently walk around the classroom and look at the variety of heart valve models while thinking about the question: "What patterns do you notice in the heart valve models?"
2. After students complete the gallery walk, give them time to write individual answers to the question above and/or discuss as a whole group. During whole group discussion:

* Ask students to describe patterns they noticed or anything else that they noticed while walking around the room. Students may notice both that many students arrived at similar designs and also that there were a variety of designs that met all criteria.
* Emphasize that multiple solutions existed for this problem and that multiple designs met all criteria. This could be connected to the fact that there are multiple versions of replacement heart valves and doctors decide which design to use based on patient needs.

*Main class activity: Reflection*

1. Wheel within a Wheel: The purpose of this activity is to get students reflecting on the engineering design process and their role within it by answering a series of reflection questions. Have students stand in two concentric rings with an equal number of students in each ring. Students in the outside ring should be facing in towards students in the inside ring. Students in the inside ring should be facing out towards students in the outside ring. For each question, give students in the outer ring 60 seconds to talk while the students in the inner ring listen only (i.e. don’t talk or respond). Then give students in the inner ring 60 seconds to respond to the same question, while students in the outer ring listen only. Have either the inner ring rotate one or two spaces to the left in between each question so that students have a chance to speak and listen to a variety of other students. Here is a list of possible questions you could use:
   1. What part of the engineering design process did you enjoy most?
   2. What part of the engineering design process did you find most challenging?
   3. What did you specifically contribute to the engineering design process?
   4. Common symptoms of a poorly functioning heart valve include tiredness, shortness of breath, and muscle fatigue. Explain how a poorly functioning heart valve could lead to those symptoms.
   5. Imagine that your engineering design team is continuing this project and you are trying to secure funding to continue developing your heart valve model. What would your next steps be? For example, what additional research would you do? What test might you perform? How might you let investors know about your research?
   6. If you were in charge of hiring a design team, would you select your own team? Why or why not?
   7. In this project, you imagined yourself as a biomedical engineer. What other science and/or engineering career do you think you would enjoy? Give reasons for your answer.
2. After the Wheel within a Wheel activity, provide students with time to silently respond to the reflection questions in step 7 of the student packet. Responding in writing to the reflection questions could be pushed to the next class period or assigned as homework if there is not enough time in class to complete it.
3. Collect student packets. If you are giving a group grade, have all students in each group paperclip their packets together.

*Conclusion: Reviewing the Engineering Design Process*

Whole class discussion: Select one or two of the reflection questions and have students respond as a whole class. Discuss the many career possibilities found within the engineering design process. Review the engineering design process and how that provided a pathway for problem solving that can be applied in many situations.

**Assessment:**Teacher listens to student responses to reflection questions during wheel-within-a-wheel activity and during whole class discussion. Teacher collects student packets and reads through reflection responses.

**Accommodations:**Students are given a variety of ways to respond to reflection questions: writing silently on their own and answering questions with partners and in whole class discussion.

**Extensions:**Students can be asked to think more deeply about the next steps involved in the engineering design process (redesign, further testing, marketing their design to investors, etc.) and could be asked to create a poster outlining those steps or presenting their design and research.

**References/Resources:**

All of the lessons/units below are from [www.teachengineering.org](http://www.teachengineering.org). We used these lessons as sources to help us develop this PBL.

“Saving a Life: Heart Valve Replacement”

<https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_heartvalves/cub_heartvalves_lesson01_activity1.xml>

“Engineering the Heart: Heart Valves”

<https://www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_heartvalves/cub_heartvalves_lesson01.xml>

“Model Heart Valves”

<https://www.teachengineering.org/view_activity.php?url=collection/van_/activities/van_heartvalves/van_heartvalves_lesson02_activity1.xml>

“Put Your Heart into Engineering”

<https://www.teachengineering.org/view_lesson.php?url=collection/duk_/lessons/duk_heartvalve_tech_less/duk_heartvalve_tech_less.xml>

“No Valve in Vein”

<https://www.teachengineering.org/view_activity.php?url=collection/duk_/activities/duk_valvedesign_tech_act/duk_valvedesign_tech_act.xml>

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