ENGINEERING DESIGN ACTIVITY: CONSTRUCTING AN AQUEDUCT
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**THIS LESSON WAS DEVELOPED IN COLLABORATION WITH THE FOLLOWING EARTHECHO EXPEDITION FELLOWS:**

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This design challenge is in support of launching your students from passive to active learners through a cross-curricular, hands-on team challenge in direct correlation to real world issues of water conservation. This lesson will allow your students to understand what an aqueduct is through a close reading activity. Students are then given different scenarios in an engineering design challenge to create an aqueduct to get freshwater to their city with different obstacles in their way. This design challenge is a great hands-on way for your students to learn more about water and water transport.

**SUMMARY**

1. **Subject(s):** Science, Technology, Engineering, and Math
2. **Topic or Unit of Study:** Water Transport
3. **Grade/Level:** 6-8
4. **Objective:** As a result of these activities, students will be able to:
   a) Understand that water is a key element for life on Earth and that human population growth is a major contributor to water scarcity.
   b) Analyze how the movement of water from one area to another may have both long and short-term consequences for the health of people and the natural environment.
   c) Describe how building techniques that were used by the Romans are still in use today.
   d) Design and build an aqueduct that will move water from its source, over a distance, to its destination using gravitational potential energy and kinetic energy conversions.
5. **Time Allotment:** 5 Periods of 55 minutes
Water covers 70% of our planet, and it is easy to think that it will always be plentiful. However, only 3% of the world’s water is freshwater, and two-thirds of that is tucked away in frozen glaciers or otherwise unavailable for our use. As a result, some 1.1 billion people worldwide lack access to water, and a total of 2.7 billion find water scarce for at least one month of the year. Water scarcity is both a natural and a human-made phenomenon. There is enough fresh water on the planet for seven billion people, but it is distributed unevenly and too much of it is wasted, polluted, and not sustainably managed.

Many of the water systems that keep ecosystems thriving and feed a growing human population have become stressed. Rivers, lakes, and aquifers are drying up or becoming too polluted to use. More than half the world’s wetlands have disappeared. Agriculture consumes more water than any other source, and some of that is wasted through inefficiencies. Climate change is altering patterns of weather and water around the world, causing shortages and droughts in some areas and floods in others. At the current consumption rate, this situation will only get worse. By 2025, two-thirds of the world’s population may face water shortages.

Throughout time, humans have relied on local water sources for their daily needs. Before the development of aqueduct technology, Romans, like most of their contemporaries in the ancient world, relied on local water sources such as springs and streams, supplemented by groundwater from privately or publicly owned wells, and by seasonal rain-water drained from rooftops into storage jars and cisterns. The reliance of ancient communities upon such water resources restricted their potential growth. By the early Imperial era, the city’s aqueducts supported a population of over a million, and an extravagant water supply for public baths and fountains had become a fundamental part of Roman life. The run-off of aqueduct water scoured the sewers of cities and towns. Water from aqueducts was also used to supply villas, ornamental urban and suburban gardens, market gardens, and farms and agricultural estates, the latter being the core of Rome’s economy and wealth.

In modern times, the largest aqueducts of all have been built in the United States to supply the country’s biggest cities. The Catskill Aqueduct carries water to New York City over a distance of 120 miles (190 km), but is dwarfed by aqueducts in the far west of the country, most notably the Colorado River Aqueduct, which supplies the Los Angeles area with water from the Colorado River nearly 400 km to the east, and the 701.5 mi (1,129 km) California Aqueduct, which runs from the Sacramento-San Joaquin River Delta to Lake Perris. The Central Arizona Project is the largest and most expensive aqueduct constructed in the United States. It stretches 336 miles from its source near Parker, Arizona to the metropolitan areas of Phoenix and Tucson.
From a historical and engineering perspective, aqueducts fill the need of moving water from a plentiful source to an area of need. However, as human population increases and there are more demands placed on freshwater resources, access to that water becomes contentious. Since the 1950s, the Sacramento-San Joaquin Delta has served as the great hydraulic tie between northern and southern California: a network of rivers, tributaries, and canals deliver runoff from the Sierra Mountain Range’s snowpack to massive pumps at the southern end of the Delta. From there, the water travels through aqueducts to the great farms of the San Joaquin Valley and to the massive coastal cities. Without this movement of water, the current level of agricultural production in the southern San Joaquin Valley could not be sustained, and many cities, including the three largest on the West Coast—Los Angeles, San Diego, and San Jose—would have to come up with radical new water supply solutions.

Many say that too much is being asked of the Delta. The levees that define the region’s water channels are aging, and geologists and climate scientists worry that earthquakes or rising sea levels could rupture them. More immediately, the Delta ecosystem is collapsing. Native fish species are on the brink of extinction in part because of this massive water-transfer apparatus. The unnatural flows disrupt their natural habitat, and when they reach the pumps—which they often do, despite the state’s efforts—they die. The Delta smelt population, for instance, has gone from hundreds of thousands to tens of thousands in the last few decades.

While using this aqueduct activity, it is important to frame it within the storyline of how increases in human population and our per-capita consumption of natural resources impact Earth’s systems. All human activity draws on natural resources and has both long and short-term consequences, positive as well as negative, for the health of people and the natural environment.
**Engage**

1. Direct Instruction: Show the students 2 images of aqueducts (one ancient and one modern).

![Aqueducts](image)

2. From what you’ve seen and read, do you know what either of the structures are and what purpose they each serve?

3. What technological advancements would be required for each of these structures to work as intended?

4. Have you learned or heard about aqueducts before? Who built aqueducts? Are people using aqueducts today? How do aqueducts transport water?

5. Connect the lesson to a real world situation by describing the engineering challenge to the class. “You are the chief water engineer hired by a city facing a severe water shortage problem. Your challenge is to build an aqueduct that is able to supply the city with clean water for use in private homes, public buildings, city parks, and crop irrigation. If you succeed, the citizens will be able to drink clean water and work happily. If you fail, there’s no telling what the citizens will do.”

6. Explain that the best design is the one that uses fewest materials, has the least amount of impact on the natural environment, and delivers water continuously with no spills and little leftover water.
Explore

Close Reading of “Aqueducts - Did you know?”

ACTIVITY 1: Aqueducts - Did you know?
A. Instruct students to read page once through with no writing
B. Number each paragraph
C. Put lines between each paragraph
D. Read again as you do
   • Highlight key terms (no more than 10 for this text)
   • Circle 5 words you do not understand after reading the text
   • Star 3 powerful verbs
   • Summarize each paragraph in one sentence
   • Underline names of sources in text

ACTIVITY 2: Demonstration of Aqueduct Design
Depending on your class size, assign 4 or 5 students to each heterogeneous team and give each group one of the 3 possible scenarios.

Describe the challenge to the class and show them the materials they will be using. (See Sample Set-Up Below)

Clarify Project Requirements and Initial Prototype Design: (Use Aqueduct Design - Student)
**Student Materials**

- empty 2-liter soda bottle with a 3/8-inch hole in the top of the bottle cap
- bucket
- 1.5 meters duct tape
- pre-cut 2 meters of vinyl tubing with 3/8-inch outside diameter
- cardboard boxes (various sizes for structure)
- table (various sizes for structure)
- chair (various sizes for structure)
- blocks or books (various sizes for structure)
- 2 liters of water—students need to have access to a water source
- scissors (to cut tape, NOT to cut the tubing)
- copies of student handout, “Constructing an Aqueduct” pg 1
- set up an example of a course that the water will transport through from the source to a bucket on the floor 5 feet away with an obstacle of books between (See Attachment 1)
- post-its
- rulers
Possible Scenarios:

**SCENARIO #1 - AQUEDUCTIS IS THIRSTY!**

**SCENARIO #2 - WATER DELIVERY TO SEAPORT CITY OF OCEANUS**
SCENARIO #3 - HILLS OF ROME

Use *Aqueduct Project Requirements and Criteria Student Handout* for the following information:

- Students must deliver the water from the bottle at point A to point C, the city. Since neither the sheet plastic nor the tubing is self-supporting, the aqueduct must go through point B, the bottom of the “valley” (the floor).
- The water flow should go through the plastic tubing from the bottle to the bucket on the floor, with lost water represented by unsupported tubing. Water is precious, so any that escapes the system represents a costly mistake in engineering, construction, and/or operation.
- Different elements may be built along the aqueduct such as a covered trench, tunnel, pressurized pipe, wall, or arcade.

Explain that certain criteria must be met (these are in the student handout). These include:

- A limit on the amount of water lost (dripped). A good place to start is a cup of water lost maximum (~15% of a full 2-liter bottle). This value may be varied, but the idea is to give students a performance limit.
- A limit on the amount of material available. Keep the materials given to each group consistent. Material (monetary) constraints are very important in engineering.
- A time limit for construction. Give students roughly 45 minutes to complete their first iteration.
- A time limit on the flow of water. If the water does not flow quickly enough, the citizens may not have a sufficient supply. Set this at 30 seconds initially for the full 2 liters, and vary accordingly.

Have teams study their scenario and then draw out their design for their aqueduct. All designs must have a scale, such as 1 inch = 10 feet or 3 cm = 10 feet. It will be easiest for students if you provide a scale.
Designing

• INDIVIDUAL - Provide 10-15 minutes of individual time to work. Be sure to remind students to clearly label their design with features (wall, arcade, etc.), include a SCALE, and practice mentally what they will say about their design.

• GROUP - Such as each students has 1 minute to explain their design and 2 minutes to take questions from their group members.

• CONSENSUS - Once all members have shared, come up with a basic idea to test

• TEACHER PRESENTATION - Groups give teacher oral presentation of initial plan.

• Provide each group a **Rubric for Performance Assessment** and an **Engineering Design Process sheet**. If you have not gone over engineering design with your students, this is a simple way to start.

Once students have built their aqueducts, they should test their design and determine what changes might increase the efficiency of the aqueduct.

Explain

Have student teams prepare a short presentation explaining how they approached the design of their aqueduct. They should discuss the aqueduct components they used and why they were the best choice based on their scenario. This can be done using a protocol called One Stay, Three Stray Instructional Strategy (one student presents to three students from a different group while the three other team members visit another team’s presentation) or as a presentation to the whole class.

If you recognize student misconceptions related to the science concepts discussed by the students, take some time help students work through these misconceptions. Some of the investigation questions you can use with the students to guide discussion include:

• What techniques can be used if mountains and valleys exist between the water source and the city?
• How is today’s water system similar or different from that of the Romans?
• What are some major constraints for this project? Do you think these existed for the Romans as well?

Elaborate

After completion of the challenge, modify the course to make it more difficult. Ask students to suggest some of the problems a community might face if the nearest water source is located far from their city. Student examples might include large stretches of agriculture competing for the same water, forests or protected/fragile ecosystems that might face damage during construction of an aqueduct. Ask students how that challenge could be represented in their scenario. Based on their previous design, have them adapt their design to solve one of the new problems presented.
Evaluate

Have students reflect on what they learned while completing this project. They should consider the engineering process and how ancient technologies can still be used today to solve problems.

Have students consider and research how their local water usage links to human activities, or what short and long-term consequences political decisions have on on this natural resource.(See Additional Resources)
Aqueducts are one of the wonders of the Roman Empire. These graceful structures were constructed to convey water, often from distant sources, and are viewed as engineering marvels that survive to this day. Aqueducts moved water through gravity alone, usually along a slight overall downward gradient within conduits of stone, brick, or concrete, but sometimes through steeper gradients. In modern times, the largest of all aqueducts have been built in the United States to supply the country’s biggest cities. Communities in Arizona, California, Hawaii, Idaho, Indiana, Massachusetts, New Mexico, New York, Texas, Washington D.C., and Washington state currently use aqueducts. The simplest aqueducts are small ditches cut into the earth, while much larger channels or pipelines may be used in modern aqueducts.

California has more than a dozen working aqueducts to supply water for people and agriculture. One of the oldest aqueducts in California supplies water to Los Angeles. By 1904, the population of Los Angeles had grown to 175,000 people and the Los Angeles River served as a water supply for the growing city. For 10 straight days that summer, water consumption in Los Angeles exceeded river capacity by more than 4 million gallons (about 15,141,647 liters). Finding an alternative water source became a top priority, and with an abundance of water just outside the city, aqueducts proved to be the answer. Even today, the Los Angeles aqueducts are a feat of engineering as amazing as those in ancient Rome. Relying entirely on gravity, the two Los Angeles aqueducts today carry about 430 million gallons (1,627.7 megalitres) of water over hundreds of miles into Los Angeles every day.


**Team Design Challenge: Constructing an Aqueduct**

In this engineering design task, “Constructing an Aqueduct,” your team has been hired by a city in crisis to solve a severe fresh water shortage due to water scarcity.
These guidelines MUST be followed for your design challenge:
- You may only use those materials on your provided list.
- Your entire plan must be completed before you begin.
- **Water loss limit:** for every 250 mL of water lost you will lose one point off the performance rubric.
- Two full liters of water must be removed between 30 and 40 seconds, or you will lose one point off the performance rubric.

These requirements MUST be met in order to have a successful design challenge:
- Water must leave the bottle at point “A” and flow towards point “C” (the city).
- Water should flow through the plastic tubing from the bottle to the bucket on the floor.
- Different elements may be built along the aqueduct such as a covered trench, tunnel, pressurized pipe, wall, or arcade.

IMPORTANT TO KEEP IN MIND:
- In order for the citizens to have sufficient water supply, the water must flow quickly.
- Water is precious. Any water that escapes the system represents a costly mistake in engineering, construction, and/or operation.

Good luck!
SCALE OF PROTOTYPE: ________  = ________

**Directions:** Draw prototype design below. Use pencil. Label as much as possible, including your scale.
# Aqueduct Design

## Identified Problem:

- Water must flow from the bottle at point A to the “city” at point C.
- The water flow should go through the plastic tubing from the bottle to the bucket on the floor.
- Water is precious, so any that escapes the system represents a costly mistake in engineering, construction, and/or operation.
- Different elements may be built along the aqueduct such as a covered trench, tunnel, pressurized pipe, wall, or arcade.

## Requirements

- Water loss limit. Every 250 mL of lost water represents a point decrease in the performance rubric.
- You may use only those materials on your list.
- Your entire design plan must be completed before you begin.
- If the water does not flow quickly enough, the citizens may not have a sufficient supply. The full 2 liters must be removed between 30 and 40 seconds. Inability to meet this flow rate will result in a point decrease in the performance rubric.

## Criteria

- empty 2-liter soda bottle with a 3/8-inch hole in the top of the bottle cap
- bucket
- duct tape
- pre-cut 5 feet of vinyl tubing with 3/8-inch outside diameter
- cardboard boxes (various sizes)
- table
- chair
- blocks or books
- 2 liters of water-students need to have access to a water source
- scissors
Rubric

Use the Aqueduct Engineering Assessment Rubric to assess student work on the engineering project. Criteria include testing of knowledge and concepts, design and construction of aqueduct, and operation of aqueduct.

**AQUEDUCT ENGINEERING ASSESSMENT RUBRIC**

<table>
<thead>
<tr>
<th>Identifying the problem(s) and brainstorming solutions</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Showed a clear understanding of the problem(s) to solve. Independently brainstormed solutions.</td>
</tr>
<tr>
<td>20</td>
<td>Needed some teacher direction to define the problem(s) and brainstorm possible solutions.</td>
</tr>
<tr>
<td>10</td>
<td>Needed lots of teacher direction to define the problem(s). Little if any independent brainstorming.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Working as a team member</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Worked well together. All team members participated and stayed on task.</td>
</tr>
<tr>
<td>15</td>
<td>Some team members were occasionally off task.</td>
</tr>
<tr>
<td>10</td>
<td>Most team members were often off task and not cooperating or participating fully.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Using the design process</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Team brainstormed main design ideas and tested and improved the design. Final design complete or nearly complete aqueduct (including covered trench, tunnel, pressurized pipe, wall, or arcade), with no material wasted and shows creative problem solving.</td>
</tr>
<tr>
<td>15</td>
<td>Some team members were occasionally off task. Final design showed only some elements of an aqueduct (covered trench, tunnel, pressurized pipe, wall, or arcade), with few additional materials obtained.</td>
</tr>
<tr>
<td>10</td>
<td>Team brainstormed few design ideas and did little testing or redesigning. Final design lacks aqueduct elements (covered trench, tunnel, pressurized pipe, wall, or arcade), with significant materials wasted.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processing the science and engineering</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Team gave a strong presentation of its solution to the challenge and showed clear understanding of the science concepts and design process. The team removed the full 2 liters in less than 30 seconds.</td>
</tr>
<tr>
<td>10</td>
<td>Team gave a basic presentation of its solution to the challenge and showed basic understanding of the science concepts and design process. The team removed more than 85% of the original amount within 30 seconds.</td>
</tr>
<tr>
<td>5</td>
<td>Team gave a weak presentation of its solution to the challenge and showed little understanding of the science concepts and design process. The team removed less than 85% of the original amount within 30 seconds.</td>
</tr>
</tbody>
</table>

**Total**
RESOURCES

1. Show students the following video clip of Philippe Cousteau and The California Aqueduc [http://earthecho.org/educator-resources](http://earthecho.org/educator-resources)

2. Choose from the Teacher Resources 1-2 (reading/visual) texts sources for students to gather information about aqueducts to build background knowledge. Post resources on Google Classroom or a student platform you use to post assignments. Have students write their name, title of the resource, and paraphrase what they learned on a post-it. Display post-its on a bulletin board. (10 mins.)

   - Interactive Drinking Water Map by the EPA [https://geopub.epa.gov/DWWidgetApp/](https://geopub.epa.gov/DWWidgetApp/)
   - Archaeology: How a Roman Aqueduct Works [http://archive.archaeology.org/1203/features/how_a_roman_aqueduct_works.html](http://archive.archaeology.org/1203/features/how_a_roman_aqueduct_works.html)
   - The Roman Aqueducts – YouTube [https://www.youtube.com/watch?v=oTMrfyAt6Mo](https://www.youtube.com/watch?v=oTMrfyAt6Mo)
   - Roman Water Supply – Strip the City YouTube [https://www.youtube.com/watch?v=pAUgodcXyWQ](https://www.youtube.com/watch?v=pAUgodcXyWQ)

CITATIONS

- Reference: “Aqueduct.” Aqueduct - New World Encyclopedia, [www.newworldencyclopedia.org/entry/Aqueduct](http://www.newworldencyclopedia.org/entry/Aqueduct)


EDUCATIONAL STANDARDS

NGSS STANDARDS

Performance Expectations

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Science and Engineering Practices

Planning and Carrying Out Investigations - Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions.

Disciplinary Core Idea

PS3.A Definitions of Energy - A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)

Crosscutting Concepts

Systems and Models - Models can be used to represent systems and their interactions

Energy and Matter - Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). (MS-PS3-5)