Float a Boat

Design Challenge Learning

The Tech Museum of Innovation

201 S. Market St.
San Jose, CA 95113
1-408-294-8324
thetech.org

Students draw upon their understanding of buoyancy and density, as well as potential and kinetic energy, to design and build a floating vessel with its own propulsion system that will carry cargo across a wading pool. As students iterate through the design challenge, they gain firsthand experience in the design process.

Grades 3-8
Estimated time: 3 Sessions (45 minutes)

Student Outcomes:

1. Students will be able to describe a Buoyant Force as an upward force exerted by a fluid on a submerged object.
2. Students will be able to apply the concepts of buoyancy, density, and the balancing of forces to create a device that is capable of floating.
3. Students will be able to utilize their knowledge of Potential and Kinetic Energy in order to design a system to propel their water vehicle.
4. Students will be able to utilize the three step design process to meet an engineering challenge.

Next Generation Science Standards
Grade 3-5: *Engineering Design* 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3
Grade 3: *Physical Science* 3-PS2-1
Grade 4: *Physical Science* 4-PS3-4
Grade 5: *Physical Science* 5-PS1-1
Grade 6-8: *Engineering Design* MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4; *Physical Science* MS-PS2-2

Common Core Language Arts-Speaking and Listening
Grade 3: SL.3.1b-d, SL.3.3, SL.3.4a
Grade 4: SL.4.1b-d, SL.4.4a
Grade 5: SL.5.1b-d, SL.5.4
Grade 6: SL.6.1b-d
Grade 7: SL.7.1b-d
Grade 8: SL.8.1b-d

California Science Content
Grade 3: *Investigation and Experimentation* 5.a-b, 5.d
Grade 4: *Investigation and Experimentation* 6.a-d
Grade 5: *Investigation and Experimentation* 6.b-e, 6.h
Grade 6: *Investigation and Experimentation* 7.a-b, 7.d-e
Grade 7: *Investigation and Experimentation* 7.a, 7.c, 7.e
Grade 8: *Physical Science* 2.a-f, 8.a-d; *Investigation and Experimentation* 9.a-b

Vocabulary:

Familiarity with these terms and concepts will enhance students' experience in the activity.

- Archimedes Principle: The relationship between buoyancy and displaced fluid: An immersed object is buoyed up by a force equal to the weight of the fluid it displaces.
- Boyle's Law: At a constant temperature, the volume of a given quantity of gas is inversely proportional to the pressure upon the gas.

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- Buoyancy: An upward force acting on an immersed or floating body by the supporting fluid.
- Buoyant Force: The net upward force exerted by a fluid on a submerged object.
- Density: A property of a substance, equal to the mass divided by the volume; commonly thought of as the lightness or heaviness of a substance.
- Displaced: Term applied to fluid that is moved out of the way when an object is placed in the fluid.
- Elastic Potential Energy: Potential energy due to tension – either stretch (rubber bands, etc.) or compression (springs, etc.).
- Energy: The ability to do work. Appears in many forms, all of which are either kinetic or potential.
- Equilibrium: A state of balance between opposing forces.
- Fluid: Anything that flows; any liquid or gas.
- Force: A push or a pull. An influence on a body or system, causing or tending to cause a change in movement or shape.
- Gravity: A pulling force exerted by any mass upon another.
- Inertia: The tendency of matter to remain at rest if at rest, or, if moving, to keep moving in the same direction, unless affected by an outside (or unbalanced) force.
- Kinetic Energy (KE): Energy of motion. Includes heat, sound, and light (motion of molecules).
- Mass: The amount of matter that is contained by an object.
- Momentum: The quantity of motion of a moving object, equal to the product of its mass and its velocity.
- Neutral Buoyancy: Exists when the weight of the body is equal to the weight of an equal volume of the displaced fluid. The body remains suspended – neither rising nor sinking – unless acted upon by an outside force.
- Potential Energy (PE): Energy of position; energy that is stored and held in readiness. Includes chemical energy, such as fossil fuels, electric batteries, and the food we eat.
- Pressure: The force per unit of surface area; exerted perpendicular to the surface; measured in Pascals.
- Principle of Flotation: A floating object displaces a weight of fluid equal to its own weight.
- Speed: How fast an object is moving. The distance traveled over time.
- Velocity: The speed of something in a given direction.
- Volume: The amount of space enclosed by a shape or object; how much 3-dimensional space (length, width, and height) it occupies.
- Weight: The downward force caused by gravity on an object.

Resources:

- The Wind-Powered Commuter Ferry: An article from Popular Science that explores a new High Tech Wing that can be utilized on ferries in order to cut diesel consumption by 40%. The design was developed by a company out of Napa, CA that was exploring options for providing greener transportation on the San Francisco Bay. www.popsci.com/wind-powered-commuter-ferry-built-racing-boat
- Buoyancy: A quick overview of how things float and key buoyancy concepts. www.seaperch.org/article?article_id=313
- Mythbusters: "Let's Talk Buoyancy": A video where the Mythbusters explain buoyancy and relate it to a pirate myth of turning a rowboat into a submarine. www.discovery.com/tv-shows/mythbusters/videos/lets-talk-buyoyancy/
- Buoyancy Playground: A buoyancy simulator supported by the University of Colorado Boulder that allows you to manipulate different experimental parameters including mass, volume, density, and fluid. The simulator provides quantitative measurements and allows you to overlay force vectors onto the simulation. http://phet.colorado.edu/sims/density-and-buoyancy/buoyancy_en.html

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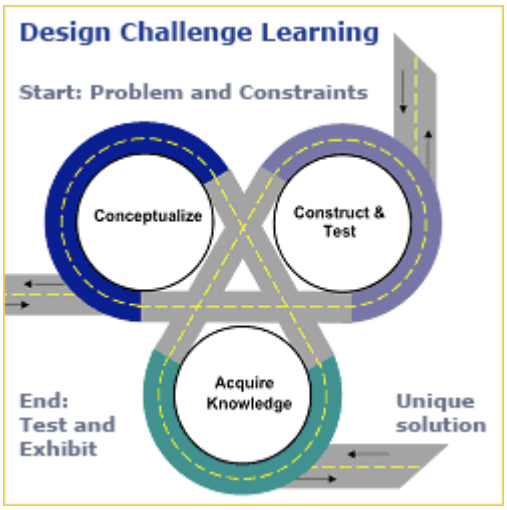
Design Challenge Process:

The Design Challenge Process is designed so students reinforce their science, mathematics, social studies, and language arts content knowledge, through an open-ended process that results in an original, team-driven solution. Students are expected to take responsibility for assessing their own progress and incorporate peer feedback as they conceptualize and redesign their projects.



The process consists of three interconnected steps:

Conceptualize
- Identify problem, materials, and constraints
- Brainstorm ideas and possible solutions

Construct and Test
- Select a solution
- Design and construct
- Prototype
- Redesign or modify
- Retest

Acquire Knowledge
- Research
- Share solutions
- Reflect and discuss

Through the try, fail, learn approach, students develop skills and habits of mind of Silicon Valley innovators: creativity, problem solving, design, collaboration, leadership, risk-taking, perseverance, and learning from failure.

Materials:

Materials can be limiting or inspirational to students! Have a wide variety of materials to promote a diversity of solutions. "Recycled items" are really useful: old mouse pads, wood scraps, boxes, cardboard tubes, strawberry baskets, etc.

Class Supplies to Share:

- Plastic Bottles
- Foam Plates & Bowls
- Milk Cartons (various sizes)
- Petri Dishes
- Pieces of Stiff Foam
- Styrofoam Peanuts
- Bubble Wrap
- Craft Sticks
- Balloons
- Rubber Bands
- Plastic Propellers
- Paper Clips
- Aquarium Tubing
- Thumbtacks
- Pins
- Plastic Straws
- Aluminum Foil
- Saran Wrap
- Tape (masking, packing)
- Pipe Cleaners
- Scissors
- X-acto Knife (for facilitator)
- Tarp
- Pennies (10-20 per team)
- Construction Paper
- Small Inflatable Wading Pool (testing)

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Lesson Plan:

Introduction *(10 minutes)*

1. It is anticipated that by the year 2030 approximately 218,600 commuters will need to travel from the East Bay in order to get to work in San Francisco.[1] Furthermore, it is expected that the number of commuters from all parts of the bay to San Francisco will only continue to climb. This is putting a strain on the area's infrastructure such as roads, bridges, and mass transit services, as well as contributing to the issues surrounding the use of fossil fuels.
2. How does the Bay Area commute relate to issues of global climate change? What are some ways to mitigate this problem? *Note: Guide students toward solutions that include mass transit and shorter routes.*
3. Utilizing a map of the Bay Area help the students plot and measure routes from different locations in the East Bay to San Francisco. Encourage them to consider those routes that are via roads and routes that are not. What is the fastest way to San Francisco from Oakland and Berkeley? *Answer: Directly across the Bay.*

Design Challenge #1: Float A Boat First-Attempt *(35 minutes)*

1. Introduce the Challenge: The San Francisco Bay Area is looking at mass transit options that will transport large numbers of people via short routes across the Bay. Design an efficient water-based vessel that can hold as many passengers (pennies) as possible while gliding across the water using its own power.
2. Introduce the Constraints:
    - Your vessel must be able to hold at least 10 pennies (more for older students) without sinking.
    - Your vessel must float on the water and be stable.
    - Your vessel must be able to float from one end of the pool to the other.
    - Your vessel must be self-propelled; it must be capable of storing energy.
    - Your vessel must be reliable.
3. Build: Give students about 20 minutes to build. Instructor should ask open-ended questions to help guide students through the design process, but should also allow students space to tinker. Students should be allowed to test their design during the building process.
4. Testing: Students should be allowed to test their design in the pool during the 20 minute building block. In order to test, students place their vessel at one end of the wading pool. After making sure that the vessel can hold the designated number of pennies, it should be sent off to the other side. The vessel needs to be tested at least two times.
5. Demonstration: Have students demonstrate their vessel designs in the pool one at a time. The other teams should watch each demonstration and consider what went well and what can be improved in each of the designs.
6. Reflection: Have each group of students explain their design strategy and how their vessel propels itself across the water. The instructor should ask leading questions to get at the science behind the design:
    - How does your design store energy to be propelled across the pool?
    - What changes did you make to your design in order to improve stability?
    - What changes did you make to your design in order to improve buoyancy?
    - How would you change your design if you had to transport more pennies?
    - How would you change your design if the vessel needed to move more quickly across the pool?

[1] Planning Section of the Metropolitan Transportation Commission, *Commuter Forecasts for the San Francisco Bay Area 1990-2030 Based on ABAG Projections 2003 and Census 2000 Data Summary,* Oakland, CA, May 2004. Retrieved on 16 June 2015 from http://www.mtc.ca.gov/maps_and_data/datamart/stats/Commuter_Forecasts_Data_Summary_May2004.pdf

- If you had more time what would you change about your design in order to improve its performance?

Directed Instruction (Density, Buoyancy, and Energy) *(30-45 minutes)*

1. Teaching Points:
   - Density is an object's mass divided by its volume.
   - Buoyant Force is the net upward force exerted by a fluid on a submerged object.
   - Potential Energy is stored energy and Kinetic Energy is energy in motion.
   - Law of Conservation of Energy as it relates to renewable and non-renewable energy sources.
2. Density is the amount of mass per unit volume. If you increase the mass but keep the volume the same, the density increases. If you increase the volume but keep the mass the same, the density decreases. When something is denser than water, it is negatively buoyant. When it is less dense than water, it is positively buoyant and will float.
   - Demonstration: Show students a small (1-2 cup) plastic container filled with marbles. Discuss that it has a lot of stuff (mass) in a small shape (volume). Ask them to predict whether it will sink or float. Empty the marbles into a larger container (16 times larger than the smaller container). Stress that this is the same amount of mass in a larger volume. Ask them to predict whether it will sink or float.
   - Mini-Challenge: Floating Clay: This activity encourages students to see how shape and size (volume and density) affects an objects ability to float (buoyancy).
     - Give students a 2-inch diameter ball of clay. Have them put it in a water tank (plastic container). What happened?
     - Have the students retrieve the clay and dry it off. Give the students a couple of minutes to make the same piece of clay float (without adding or taking away).
     - *Note: Some students will find that a flat circular shape will float. Others may begin forming the clay into more of a boat shape, making it a little deeper.*
     - Reflect: Ask students how they made the clay float? Reflect upon the fact that clay sinks when its volume or size is smallest, however it will float when its surface area or volume is increased significantly. Try to get the students to come up with the idea that shape matters.
3. Potential Energy is stored energy and Kinetic Energy is energy in motion.
   - Demonstration: Utilize a ball to visually define the difference between Potential and Kinetic Energy. Place the ball on the ground to represent an item with no gravitational potential energy and no kinetic energy. Hold the ball high up to represent an item with gravitational potential energy. Drop the ball to represent an item with kinetic energy. Challenge the students to identify Elastic Potential and Kinetic Energy in a rubber band.
4. Law of Conservation of Energy states that the total amount of energy in a system remains constant ("is conserved"), although energy within the system can be changed from one form to another or transferred from one object to another. Energy cannot be created or destroyed, but it can be transformed.
   - Demonstration: Utilize Newton's Cradle to demonstrate how Gravitational Potential Energy can become Kinetic Energy and that Kinetic Energy can be transferred to another object. The instructor should ask leading questions to get at the science behind the cradle. Students can interact with an online simulator found at: www.lhup.edu/~dsimanek/scenario/newton.htm
   - Mini Cognitive Challenge: Have the students consider the energy contained in a cell phone. Ask the students to map the different forms the energy took in order to get to its current form. Ask the students to make a list of all the ways the energy stored in the phone transferred/changed in

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order for the battery to go dead. *Note: Challenge students to trace the energy all the way back to the Sun.*

- Questions:
    - How does the Newton's Cradle work?
    - How was the energy transferred/transformed in the Newton's Cradle?
    - Why did the Newton's Cradle eventually slow down? Where does the energy go?
    - How does this Law apply to green energy?
    - How do you think a wind turbine, solar panel, water turbine, and other green energies work? Where does the energy come from?

Design Challenge #2: Float A Boat *(45 minutes)*

1. Introduce the Challenge: Redesign your vessel so that you can increase the number of pennies you can carry across the wading pool (how many pennies can you carry?).
2. Introduce the Constraints:
    - Your vessel must be able to hold at least 10 pennies (more for older students) without sinking.
    - Your vessel must float on the water and be stable.
    - Your vessel must be able to float from one end of the pool to the other.
    - Your vessel must be self-propelled; it must be capable of storing energy.
    - Your vessel must be reliable.
    - You will be required to create a sales pitch to sell your idea as a viable and green alternative form of transportation.
3. Build: Give students about 30 minutes to design and build. Instructor should ask open-ended questions to help guide students through the design process, but should also allow students space to tinker. Students should be allowed to test their design during the building process.
4. Testing: Students should be allowed to test their design in the pool during the 20 minute building block. In order to test, students place their vessel at one end of the wading pool. After making sure that the vessel can hold the designated number of pennies, it should be sent off to the other side. The vessel needs to be tested at least two times.
5. Demonstration: Have students deliver their 60 second sales pitch and demonstrate their vessel designs in the pool one at a time. The other teams should watch each demonstration and consider what went well and what can be improved in each of the designs.
6. Reflection: Have each group of students explain their design strategy and how their vessel propels itself across the water. The instructor should ask leading questions to get at the science behind the design:
    - How did you change your original design? What affect did this/these change(s) have upon the performance of your vessel?
    - How many pennies can your vessel safely carry across the wading pool?
    - Did you do anything specific to increase the buoyancy of your vessel?
    - If you had more time what would you add, change, or do differently?
    - If you were working in a 1:1 scale would you need to change anything about your design?