PHYSICAL SCIENCE LESSON PLAN - COMPOSITE

Title: Design of Experiments Project involving Concrete
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Grade Level: High School

OBJECTIVES:

• Demonstrate to students the principles of design of experiments (planning, designing and analyzing), and use them to determine the optimal composition of concrete

• To help students design a concrete boat that can carry the maximum load possible without sinking to provide students with experience in estimation, calculation and results reporting.

MATERIALS:

• rain gutter
• cement
• accelerant
• water
• sand
• aggregate
• paperclips

ANTICIPATORY SET:

Principles of Design of Experiments:
“Design of Experiments refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be drawn effectively and efficiently. In order to draw statistically sound conclusions from the experiment, it is necessary to integrate simple and powerful statistical methods into the experimental design and methodology. The success of any industrially designed experiment depends on the sound planning and appropriate choice of design, statistical analysis of data and teamwork skills.”
Reference: Jiju Antony, 2003

Determining the Optimal Gradation of Concrete Aggregates:
“In practice, concrete quality is defined by the physical condition of the hardened concrete. The state of the fresh concrete is reflected primarily by the slump test. It is not generally acknowledged that the quality of the hardened concrete depends on the quality of the fresh concrete. The proportioning of sand and coarse aggregate components has an important effect on the properties of both the fresh and hardened concrete. Unsatisfactory gradation may lead to:
1. Segregation of the mortar from the coarse aggregates.
2. Bleeding of water below and around larger aggregates and on the surface of the concrete.
3. Settling of aggregates, leaving paste in the top layer of the concrete.
4. Use of chemical admixtures in order to restore workability to the concrete.
5. Increased use of cement.
6. Insufficient air entrainment and air-void distribution.
7. Excessive use of water.
8. High porosity of the hardened concrete.
9. High material costs.
10. Reduced service life.

To prevent these undesirable conditions, it is necessary to evaluate the proportions of the different materials used.”

Reference Just Andersen and Vagn Johansen, 1993

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**ACTIVITIES/METHOD:**

**Activity 1: Concrete Bridge**

**Protocol:**
Each team will make 2 concrete test bars, with each bar being made of a different composition.

1. Mix sample concrete in a bucket. Each sample will include:
   - 2 3ft sections of rain gutter
   - 3 cups of cement
   - 3 tsp of accelerant
   - water: 1.5 or 2.25 cups
   - sand: 3 or 5 cups
   - aggregate: 0 or 1 cups
   - paperclips: 0 or 1 box

   **Note:** Make sure that the composition is as uniform as possible. Use gloves if you choose to mix by hand.

2. Tape ends of gutter with duct tape. **Be cautious about sharp edges.** Mark 1” height at the ends and middle of the inside of the gutter

3. Pour half of your mixture into the gutter. Trowel/press it smooth

4. Pour remainder of mixture into gutter, but do not exceed the 1” marks. Trowel/press it smooth.

5. Repeat for the other bars. Label each bar with the composition and team name.

**Mechanical Testing:**

We will use a simple 3-point bend test to determine the maximum load that can be supported by each bar.
1. Place bar on sawhorse, leaving 2” of each end on sawhorse. Place the smoother surface on the bottom (tensile region)
2. Add bucket with a sponge underneath between the bucket handle and bar to reduce local stress concentrations.
3. Slowly add weights until bar fractures. When adding large weights, first remove a smaller weight to increase accuracy. Record fracture load for each bar.

Critical thinking: Questions to ask students:

a. Based on the class lab results, describe the effect of varying each of the following:
   - Sand
   - Water
   - Aggregate
   - Paper Clips

b. How did your team choose to arrange the paper clips, and why?
c. How would you arrange them differently? Why?

Activity #2: Concrete Boat

Protocol:
Each team will make 1 concrete test boat.

1. Mix sample concrete in a bucket. Each sample will include:
   - 2.25 cups cement mix maximum
   - 1.75 cups of water maximum
   - 3 cups sand maximum
   - 1 box paperclips maximum
   - 2 base “molding” sections maximum

2. Make sure that the composition is as uniform as possible. Use gloves if you choose to mix by hand.
3. Use materials chosen to form a boat
4. Build boat on a base such that the boat can be easily moved to dry without damage once completed
5. Label boat or boat “base” with team name and concrete composition

Prediction of Cargo Capacity:

1. Determine Mass of boat
2. Estimate volume of water displaced by Boat when fully loaded.
3. Calculate mass of water displaced by boat: 1 cc = 1 g for water
4. Calculate cargo capacity of boat
5. Cargo capacity = Mass of water displaced by boat – mass of boat
6. Write answer on team report.

Test of Boat:
1. Place boat in water.
2. If it is still floating, load boat with cargo to determine maximum load.

Critical thinking: Questions to ask students:

a. What was your prediction of cargo capacity?
b. What was your actual cargo capacity?
c. Summarize your teams major design concept(s) – what were you trying to do with your design?
d. What do you think could be done to improve on your design?
Student Assessment:
- Students are able to determine and describe the varying effect of each material used.
- Students are able to thoughtfully explain how and why their group chose to use the paper clips.
- Students are able to thoughtfully discuss ways their experiments could have worked better.
- Students are able to determine cargo capacity for their boat and compare that to their prediction.
- Students are able to thoughtfully explain their team’s major design concepts.
- Students are able to thoughtfully consider ways their experiments may have worked better.

Arizona State Standards:
Strand 5: Physical Science
Concept 1: Structure and Properties of Matter
PO 1: Describe substances based on their physical properties
PO 4: Separate mixtures of substances based on their physical properties
Concept 2: Motions and Forces
PO 1: Determine the rate of change of a quantity (e.g., rate of erosion, rate of reaction, rate of growth, velocity).
PO 2: Analyze the relationships among position, velocity, acceleration, and time:
  • graphically
  • mathematically
PO 4: Using Newton’s 2nd Law of Motion, analyze the relationships among the net force acting on a body, the mass of the body, and the resulting acceleration:
  • graphically
  • mathematically
PO5: Use Newton’s 3rd Law to explain forces as interactions between bodies (e.g., a table pushing up on a vase that is pushing down on it; an athlete pushing on a basketball as the ball pushes back on her).
PO11: Using the Law of Universal Gravitation, predict how the gravitational force will change when the distance between two masses changes or the mass of one of them changes.

Notes:
Remember to review all safety precautions with students before beginning the activities.

To arrange for a class field trip to the LeRoy Eyring Center for Solid State Science or a visit from Science is Fun, please contact:
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