LESSON PLAN

Cost-Effective Solar Cells

Lesson #12: Unique Solar Cell Construction & Testing

AUTHOR

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DESCRIPTION

LESSON 12: UNIQUE SOLAR CELL CONSTRUCTION & TESTING

This lesson is designed to be completed in four 80-minute sections. The teacher will facilitate the construction of unique solar cells for student projects. General chemistry equipment and fabrication equipment will be needed for student construction and testing. The teacher will facilitate student note-taking and celebrating failures. The teacher will encourage students to take photos frequently to document progress and the upcoming Engineering Report in Lesson #14. Lesson #13 can break up the 4 construction days and allow students to share out obstacles and receive audience feedback. Teachers will facilitate solar cell testing indoors and outdoors. This lesson can be expanded or contracted in day number based on student progress.

- *Day 1: Construction #1*
- *Day 2: Construction #2*
- *(Optional Sequence) Lesson #13*
- *Day 3: Construction & Testing*
- *Day 4: Construction & Testing*

GRADE LEVEL(S)

9, 10, 11, or 12

SUBJECT AREA(S)

Chemistry, Physics, Solar Panels, Solar Cells, Power, Current, Voltage, Electricity Generation

ACTIVITY LENGTH

4 days X 80 minutes

LEARNING GOAL(S)

1. Students will construct their unique solar cells
2. Students will test unique solar cells
3. Students will revise procedures based on solar cell testing results
4. Students will re-build and re-test solar cells

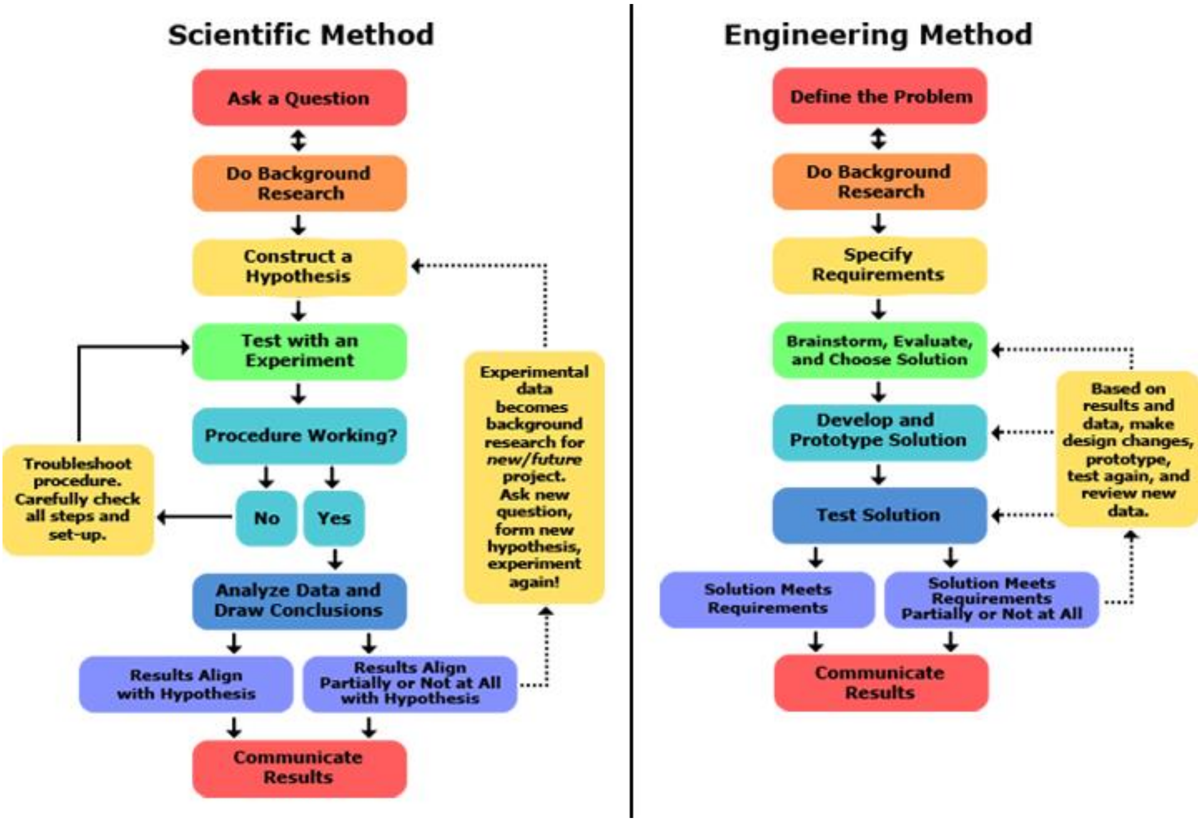
CONTENT BACKGROUND

STUDENT BACKGROUND

- Students participating in this lesson should be familiar with the following scientific practices and concepts:
  - Planning and Carrying Out Investigations
  - Design Solutions
  - Collecting, Analyzing, and Interpreting Data
  - Modifying Procedures and Designs
  - Engineering Design Process and Elements
  - Electricity Basics (Lessons 2, 4): Voltage, Current, Circuitry
  - Photovoltaic Effect in Solar PV Panels (Lesson 3)
  - Measuring Voltage and Current Using a Multimeter (Lesson 2)
  - Laboratory Safety & Emergency Procedures including disposal and chemical hazards

EDUCATOR BACKGROUND

Students will be research their own unique solar cells to design, build and test. This process will involve the concepts of solar cells taught in prior lessons, creative thinking and implement the engineering/design process. This process differs from scientific inquiry in several ways:



Both processes are reiterative and demonstrate that science and engineering are ongoing, dynamic processes. Lessons 10 begins to engage fully in the engineering method as students work with unique projects.

The key steps in the engineering design process used in this unit are as follows:

- Defining the Problem
- Performing Background Research
- Specifying Criteria and Constraints
- Designing and Modeling a Solution
- Building the Solution (Prototype)
- Testing the Solution
- Analyzing Results Within Criteria and Constraints
- Communicating Results

The Next Generation Science Standards parallel these steps with their Science and Engineering Practices, which will be used to assess students:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

In this particular lesson, students will be:

- Carrying out an Investigation (NGSS SEP3)
- Designing and Modeling a Solution (NGSS SEP6)
- Analyzing and Interpreting Data (NGSS SEP4)
- Using Mathematics & Computational Thinking (NGSS SEP5)

Students will likely choose solar cell designs that may be too complex for general high school laboratory. You may need to accommodate student ideas with safer, cheaper, or less time-consuming alternatives. Re-teaching of several concepts may need to occur due to the length of the overall unit. Here are some useful concepts that may need review:

Photovoltaic Effect: https://cebrightfutures.org/learn/photovoltaics#Photovoltaic%20Effect

Photovoltaic Materials: https://cebrightfutures.org/learn/photovoltaics#Photovoltaic%20Materials

Multimeters*:* https://cebrightfutures.org/sites/default/files/multimeter-cheatsheet.pdf

Circuit: https://cebrightfutures.org/learn/circuits

Circuit diagrams:

Circuit diagrams show a visual representation of the components of a circuit. Components have common symbols as illustrated by the below diagram (from Wikipedia)

Solar Energy: https://cebrightfutures.org/learn/solar-energy

Incident Angle of Sunlight: https://cebrightfutures.org/learn/incident-angle-sunlight

Although chemicals and materials are not needed for this lesson, the materials needed section contains some possible chemicals students may request or use. The teacher should be aware of materials that they have, can substitute, or may need to order on short notice.

MATERIALS NEEDED

HANDOUTS/PAPER MATERIALS

- N/A

CLASSROOM SUPPLIES

- Electric hot plates
- Tin snips

- Dish soap
- Stir rods or spoons
- Access to water
- Weigh boats or paper squares for dry chemicals
- Plastic cups
- Masking or clear tape
- Highlighters
- Fume hood
- Matches or lighter
- Chemical waste disposal – wet and dry
- Incandescent or halogen light bulbs of various wattages
- Popsicle sticks
- Thermometers
- 3D printer

ACTIVITY SUPPLIES (POSSIBLE STUDENT REQUESTED ITEMS)

- Titanium dioxide
- Tin oxide
- Dilute acetic acid
- Potassium tri-iodide solution
- Copper sheets or foil
- Tin sheets or foil
- Aluminum sheets or foil
- Zinc sheets or foil
- FTO (TEC15) 1” x 1” coated glass slides
- Uncoated glass slides
- Graphite
- Stannous chloride for coating glass
- Fluoride toothpaste for coating glass
- Inkjet printer / refillable ink cartridges for thin-layer printed cells
- Transparency sheets
- Heat-resistant plastic film
- Spray bottles / misters
- Methylammonium Iodide (for perovskite crystals)
- Lead Iodide (for perovskite crystals – need specialize waste disposal)
- Triphenylamine (electron hole transport)
- Choline Chloride (for chlorophyll extraction)
- DMSO (solvent)
- Glycerin (solvent)
- Ethanol (solvent)
- Binder clips
- Multimeter
- Alligator clips
- Centrifuge
- Spin coater / attachment for centrifuge
- Chemical Inventory / MSDS sheets

- Safety equipment:
    - Goggles
    - Gloves
    - Beaker and crucible tongs
    - Silicon potholders or clamshell hand grips
    - Forceps
    - Fume hoods

LESSON PROGRESSION

PLANNING AND PREP

This lesson spans four days, but may need more time depending on student engagement and depth of research. In addition, more time allows for students to build and test multiple solar cells, deepening learning and laboratory skill. On Days 1 and 2, students will mostly be constructing their initial solar cells. Many students will begin with FTO-coated glass and a titanium dioxide blocking layer. On Days 3-4, students will be continuing construction and may be testing solar cells as they finish. Depending on the progress of the students and their lessons learned from failed procedures or testing, the teacher can opt to interrupt the construction progress and have students share their obstacles and failures in Lesson 13. The students are building an engineering report and Lesson 12 focuses on the following engineering report sections:

1. Materials (revisions)
2. Procedure (revisions)
3. Design (revisions)
4. Results

To prepare for the myriad of possible projects and outcomes, here are some learned tips for overcoming solar cell obstacles:

Copper Oxide and CZTS (Copper-Zinc-Tin-Sulfide) Solar cells

- Cut out or have students cut out 1” x 1” or 1” x 2” metal sheets in advance
- Students will heat these materials in various ways
    - Directly on hot plates
    - In kilns/forges (two students did this at home under parental supervison)
    - In microwaves (one student did this at home under parental supervision)
- Have hot material handling equipment on hand—silicon potholders, tongs, cooling mats
- See Lesson #5 for more details on Copper Oxide cells

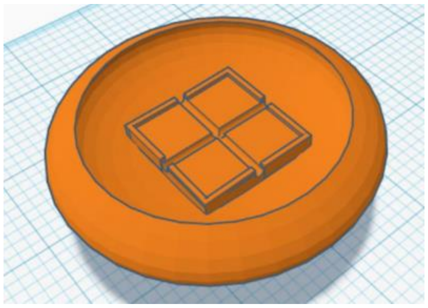
Titanium Dioxide & Light-sensitized Dye Solar Cells

- See Lesson #7 for more details on the Titanium Dioxide & Berry Solar Cells and suggested lesson extensions

- To avoid Titanium Dioxide layer cracking, use vinegar and/or dish soap in your paste. A 5 mL 0.1 M acetic acid to 3 grams of TiO_2 ratio has been successful. Also, avoid rapid temperature changes—start baking the slide on a cold hot plate and allow the hot plate and slide to cool slowly afterward.

Spin Coater

- Many solar cell procedures utilize expensive spin coating devices. A modified mini-centrifuge in the lab was adapted to make a useful spin coater. For their engineering project, one student created a 3D print of a spin coater attachment for an Edvotek mini-centrifuge that was then used by all their classmates.



Graphene / Carbon Layers

- One technique for creating a carbon layer is waving a glass slide over a lit tea candle
- One technique for creating a thin graphene layer involved suspending graphite between a layer of water and hexane (or heptane). As the hexane and water evaporated, the graphene layer remained on a glass slide.
- One technique for creating a thin graphene layer used a thick foam. Blend Dawn soap, graphite, and water together until a thick gray foam forms. Spin-coat (see above) or allow the foam to settle and dry onto the slide.

Perovskite Solar Cells

- Perovskite crystals can range from yellow to orange to gray in color. Two student teams used 1:1 ratios of Methylammonium Iodide and Lead Iodide, with added Triphenylamine to make functional solar cells.
- Perovskite crystals break down quickly in the air. Students may want to explore ways to seal the cells after the crystals form. Ideas include vacuum sealing, coating in clear acrylic nail polish, dipping in molten plastic, or storing/testing in a vacuum chamber.
- Samples of procedures for perovskite cells can be found on this student group poster: https://drive.google.com/file/d/1vi15tuKKO7LYX0OU3K9kcF0lCehfQAyN/view?usp=sharing

LESSON SEQUENCE

Day 1-4 Procedure:

1. **(80 minutes).** Allow the students ample time to construct their solar cells. Remind the students to make new procedures if necessary and to revise old procedures as they experience failures and successes. Have students record all procedures and testing data, especially paying attention to whether the cell increases power output under increased lighting conditions. Some student solar cells may act only as batteries or conductors, so careful attention should be paid towards light reactivity.

   During several points, students may need help with calculating amounts and weighing out chemicals. This is a great opportunity to teach or re-teach mole-to-gram conversions, solubility, acid-base neutralizations, and other stoichiometry problem solving.

   If appropriate, interrupt the construction & testing process of Lesson 12 to have students present initial obstacles and results in Lesson 13.

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENT

Progress on this lab activity can be monitored during the construction and testing process. Students will progress through the work at various speeds and will all need guidance in this project. Formative assessment ca be linked with NGSS SEP3—Planning and Carrying Out Investigations. Daily or Weekly status reports from students can be used to help students manage time and to monitor progress.

While students will turn in engineering reports at the end of the unit as a summative assessment, educators could gather reports and provide guidance to students and to ensure proper documentation of procedures, materials, and testing results.

SUMMATIVE ASSESSMENT

Students will be assessed on the following standards while developing their engineering reports.

- NGSS SEP3
  Planning and Carrying Out Investigations
- NGSS SEP4
  Analyzing and Interpreting Data
- NGSS SEP5
  Planning and Carrying Out Investigations
- NGSS SEP6
  Design Solutions
- NGSS HS-PS3-3:
  Design, build, and refine a device that works within given constraints to convert one form of energy into another.

LESSON EXTENSIONS

N/A