LESSON PLAN

Cost-Effective Solar Cells

Lesson #10: Researching Chemicals and Materials for Solar Cell Construction

AUTHOR

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DESCRIPTION

This lesson is designed to be completed in three 80-minute sections. The teacher will facilitate student research on solar cell designs centering around the engineering problem: How can we make a cheaper, cleaner or more efficient solar cell? Teachers should encourage students easy-to-obtain materials either found already in the Chemistry classroom, in the recommended Inquiry Materials Kit, in a local supermarket or thrift store, or to be ordered on short notice. Ideas can range from changing conditions on the copper or titanium dioxide cell process, graphite solar cells, using perovskite mineral, printable inkjet layers, organic green solar cells, to wildly creative cell designs. The teacher is encouraged to facilitate student ideas, valuing the design process more than the success or failure of the design itself. Large blocks of time are dedicated for student research, thinking, and leading towards the sketching a design model.

- *Day 1: Introduce driving question, introduce constraints, develop student success criteria, and assist in the research process*
- *Day 2: Solar cell procedures and background writing*
- *Day 3: Background writing, design and model research*

GRADE LEVEL(S)

9, 10, 11, or 12

SUBJECT AREA(S)

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

ACTIVITY LENGTH

LESSON PLAN

3 days X 80 minutes

LEARNING GOAL(S)

1. Students will research chemicals, materials and procedures for their own solar cell designs
2. Students will write an introduction to the problem, including criteria, constraints, and solar cell concepts
3. Students will research and write a rough materials and procedure for the solar cell
4. Students will research and describe their solar cell designs.

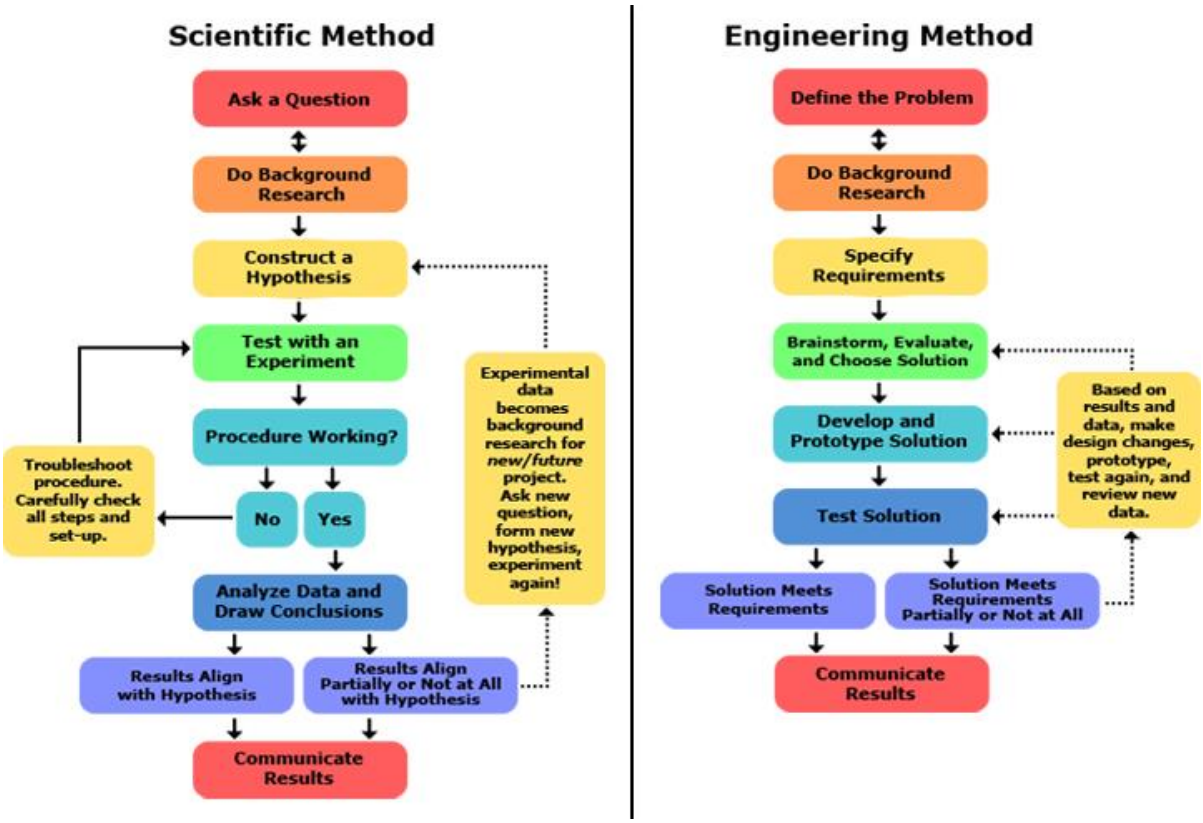
CONTENT BACKGROUND

STUDENT BACKGROUND

- Students participating in this lesson should be familiar with the following scientific practices and concepts:
    - Background research
    - Defining problems – criteria, constraints, and solar cell concepts
    - Planning and Carrying Out Investigations
    - Design Solutions
    - 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 researching 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:

- Defining the Problem (NGSS SEP1)
- Performing Background Research (NGSS HS-PS3-3)
- Specifying Criteria and Constraints (NGSS SEP1)
- Planning an Investigation (NGSS SEP3)
- Designing and Modeling a Solution (NGSS SEP6)

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, here are 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

- Materials Request Form (if needed) (https://docs.google.com/document/d/1ExDsXKk8Ro2XZGur2R2HG643D93-u3kDAGId8b3-wVs/edit?usp=sharing)

CLASSROOM SUPPLIES

- Computer access

Possible classroom supplies students may choose from:

- 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

Possible chemicals and materials:

- 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
    - These slides can be ordered here: https://www.msesupplies.com/products/fluorine-doped-tin-oxide-fto-coated-tec-15-glass-tec15-fto-can-customize-pattern-as-required?variant=19973837956

- 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

ACTIVITY SUPPLIES (PER GROUP OF 3-4 STUDENTS)

- N/A

LESSON PROGRESSION

PLANNING AND PREP

This lesson spans three days, but may need more time depending on student engagement and depth of research. On Day 1, students will write background information and establish criteria and constraints for the project. On Day 2, students will brainstorm solar cell ideas and begin research on their ideas, looking for needed materials and procedures. On Day 3, students will continue background writing and will focus on describing their design ideas. The students are building an engineering report and Lesson 10 and 11 focus on the following engineering report sections:

1. Introduction
2. Materials
3. Procedure
4. Design

LESSON SEQUENCE

Day 1 Procedure:

5. **(10-15 minutes).** Ask the students, "what are important elements to include in the introduction to an engineering report?" Have the students think about their answers for one minute. Write the question on the board (or on padlet.com, polleverwhere.com, etc.) and have students write their responses for 2-3 minutes. Highlight themes and focus the student responses down to the following ideas:
    - Reponses such as "Background," "Context," "Why," "Importance," "Relevance," "Set the stage," "Who," "What," should be grouped and redefined as:
        - ➔ **Provide background information to the reader**
    - Responses such as "Define," "Explain," "Introduce Ideas," "Details," "Relevance," "Definitions," "Science Concepts," should be grouped and redefined as:
        - ➔ **Define any needed terms or concepts**
    - Responses such as "Goals," "Product," "Success," "What are you making," "Target Audience," "Solar Cell," "Efficiency," should be grouped and redefined as:
        - ➔ **Define the success criteria**
    - Responses such as "Obstacles," "Constraints," "Costs," "Materials," "Budget," "Size," "Safety," "Things to avoid," should be grouped and redefined as:
        - ➔ **Define any constraints**
6. **(10-20 minutes).** Define the student outcomes for each of the 4 elements of the solar cell introduction.
    - **Provide background information (NGSS SEP1)**
        i. Discuss solar energy generation and the importance of solar technology
        ii. BRIEFLY discuss what you will be building and why it is important (More detail will be described later)
    - **Define any needed terms or concepts (NGSS HS-PS3-3)**
        i. Define solar cells and explain how they work
        ii. Discuss light-activated semiconductors and how they release electrons
        iii. Describe how release electrons can be used to do work
    - **Define the success criteria (NGSS SEP1)**
        i. What does success look like for your solar cell
        ii. Define the voltage output you want to see in your solar cell
        iii. Define the amperage output you want to see in your solar cell
        iv. Define other criteria such as aesthetics, "eco-friendliness", or other success observations
    - **Define any constraints (NGSS SEP1)**
        i. Define any constraints on cost (per cell)
        ii. Define any size constraints
        iii. Define any material or chemical constraints
        iv. Define any operational constraints (sun angle, lifespan of the cell, etc.)

7. **(Optional -- 10 minutes).** Have the students watch a more in-depth video on how light gets transformed into electricity using this link: https://www.youtube.com/watch?v=QrzGSwR-YXY&index=9&list=PL66flHyXj8K9gE4KLODZrkOIZUCi0fw2A. This video is "Lesson 2.1" in a 50-video series on solar cells by Arno Smets. The video series can be found here (https://www.youtube.com/watch?v=YcVe9E0EHbM&list=PL66flHyXj8K9gE4KLODZrkOIZUCi0fw2A) and contains many useful, but high level lessons on solar cells. These videos may be very useful to students as they narrow down their solar cell ideas.
8. **(35-50 minutes).** Have students begin their introduction and background writing on their unique solar cells. The section of writing on the engineering report should be labeled "Introduction." Re-assure students that they can write the introduction without having to decide on what type of solar cell to build for today's lesson. Here are a few types of cells that they can research:
    - **Copper / Copper Oxide Cells** (improving or optimizing the prior lesson)
    - **Titanium Dioxide / Anthocyanin Cells** (improving or optimizing the prior lesson)
    - **CZTS (Copper-Zinc-Tin-Sulfide) Cells**
    - **Perovskite Cells**
    - **Graphene Cells**
    - **Printable Ink Cells**
    - **Other Solar Cell Designs at the Teacher Discretion**
        - ➔ These can be solar designs that don't necessary focus on chemical layers and can include Sterling Engines, Black Body electricity, Recycled solar cells, or other creative student ideas.
        - ➔ These designs allow students to achieve engineering process goals, but not necessarily Chemistry standards and goals.

Day 2 Procedures:

1. **(5-10 minutes).** Tell the students that the Materials and Procedures they use are important and will need to be approved by the teacher for safety, complexity, time, and waste disposal considerations. Have the students research solar cell ideas using scholar.google.com or broad searches through available search engines. As they focus in on their ideas, have them generate a list of materials to share with the teacher. They should be generating a new section to their engineering report titled "Methods" OR "Materials" and "Procedure."
2. **(70-75 minutes).** Circulate the room and help students refine their ideas. Have students share their materials list and discuss potential hazards (MSDS sheets), substitutions, needed orders, and approvals. If students need to request items for ordering, have them use a Materials Request Form (https://docs.google.com/document/d/1ExDsXKk8Ro2XZGur2R2HG643D93-u3kDAGId8b3-wVs/edit?usp=sharing). After approval or conditional approval, have the students begin to write out there procedures using numbered steps.

Day 3 Procedures:

1. **(5-10 minutes).** Students should have a better idea what they need for their projects today. Have the students begin to describe their designs in terms of "layers." In a section labeled, "Design," have the students begin to describe how the layers of their solar cell will work. They should be considering the following:
    - **How the electrons / electron holes will be dislodged using light**
    - **How the electrons / electron holes will be separated after being dislodged**
    - **How the electrons / electron holes will flow into a circuit to do work**
    - **How the electrons / electron holes will return to the cell**
2. **(70-75 minutes).** Circulate the room and help students refine their ideas. Students who are progressing rapidly (ahead of others) can be asked to start thinking about the amounts of chemicals used and the techniques they will use to place layers on the cells. They can also team up with students who are still refining their ideas. Students who are struggling with ideas can be re-directed back to refining the efficiency and output of older solar cells such as the Copper/Copper Oxide or Titanium Dioxide / Anthocyanin solar cells.

ASSESSMENT AND EXTENSIONS

FORMATIVE ASSESSMENT

Progress on this lab activity can be monitored during the long stretches of student work time. Students will progress through the research and design steps at various speeds and will all need guidance in this project. Formative assessment can 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.

SUMMATIVE ASSESSMENT

Educators can gather engineering reports to assess student understanding and preparation for Lesson 11's presentations. Students will be assessed on the following standards while developing their engineering reports.

- NGSS SEP1
  Defining Problems
- NGSS SEP3
  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

As students are developing their solar cell designs, they may need support and re-teaching of concepts along the way. Here are some possible extensions to help their understanding:

Thin-layer Chromatography

- To reinforce the concepts of solutes, solvents and solutions, the students can perform thin-layer chromatography on light-sensitized dyes such as chlorophyll, anthocyanins, carotenes, and other natural pigments