Name ________________

# Climate Engineering Teaching Module
# Lesson 2: Cloud in a Bottle Worksheet

Through the experiment and this worksheet, students will learn:

- The components of a cloud.
- How clouds are created.
- How altering the components of a cloud can impact a cloud's reflectivity (albedo).
- Experiment design and data interpretation.
- The science and engineering behind the geoengineering idea called marine cloud brightening

**Question Set 1 (before Experiment One)**

1. What are the two main components of a cloud?

   *Water (or ice) and aerosol particles. Aerosol particles serve as surfaces for water vapor to condense on to form cloud droplets. These microscopic aerosol particles are called cloud condensing nuclei and can be derived from dust, soil, smoke, sea salts, and other very small particles floating in the air. Also see the PowerPoint slides and https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-are-clouds-58.html*

2. Scientists defined the term *albedo* to quantify the percentage of incoming sunlight that is reflected by an object. For example, viewed from space the Earth has an albedo of about 0.30, meaning that 30% of incoming sunlight is reflected back to space. Given this information, what do you think is the albedo of a forest, of the ocean, of a desert, of snow, of a cloud?

   *The approximate albedo of a forest is 0.15, of the ocean is 0.07, of a desert 0.27, of fresh snow is 0.95, of a cloud (0.50 – but can range from ~0.30-0.90).*

   *Using the PowerPoint slides, the teacher can show the picture of Earth alongside a table of common Earth surfaces' albedo and discuss the large role of clouds in reflecting incoming solar radiation.*

**Research Question: Can we engineer brighter Clouds?**

3. Do you think by adding additional aerosol particles, we can make clouds brighter? Why would you expect this result?

**Collecting Data**

| Experiment One: **3 Sprays** of Hairspray | | | |
|---|---|---|---|
| | Lux Meter Reading (lx) | | |
| Trial # | Bottle with Cloud | Bottle without Cloud | Difference |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| Average | | | |

| Experiment Two: **10 Sprays** of Hairspray | | | |
|---|---|---|---|
| | Lux Meter Reading (lx) | | |
| Trial # | Bottle with Cloud | Bottle without Cloud | Difference |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| Average | | | |

**Question Set 2 (after experiments)**

4. In the table, calculate the difference between the light being reflected from the bottle with and without the cloud in lux for all trials and experiments. Also, calculate the average of each column. (If calculating T-test, complete this computation with your teacher now.)

   *Use the provided Excel sheet to compute stats with students. Standard deviation and T-test statistics are optional. This is the electronic spreadsheet embedded with the equation. Students can input their data to get the results directly.* [*Lesson_Plan_2_Cloud_in_a_Bottle_Excel_Table.xlsx - Google Sheets*]

5. What were the independent and dependent variables in these experiments? What were the constants?

   *The independent variable was the number of sprays of the aerosol hairspray. The dependent variable was the amount of lux recorded by the meter. The constants were the amount of water, number of air pumps to pressurize, distance between the bottle and lux meter, light source output, plastic bottle, etc.*

6. Why did we measure and record the reflectance of the bottle after the cloud dissipated in each trial?

   *We want to find out the reflectance of each bottle w/o a cloud so that the difference in the reflectance can be attributed to just the cloud. Some of the hairspray will end up on the interior surface of the bottle and not be used in the formation of the cloud. This residue will impact the reflectance of the bottle, depending on the experiment. This procedure helps remove this source of uncertainty (how reflective is the bottle without a cloud).*

7. Explain why more aerosol particles (10 sprays vs. 3 sprays of hairspray) created a cloud that reflected more light?

   *This question will require information provided in the introduction. This information will help the students conclude that the hairspray particles provide a surface for the moisture to condense on when the stopper is pulled off the bottle. These particles and the water condensed upon them are cloud droplets. Increasing the number of cloud droplets in a cloud increases the surface area that light can reflect upon, thus creating clouds with higher albedo.*

8. How could we implement this climate engineering technology to brighten clouds on a larger scale, in the real world?

   *To expand this experimental result to the real world, you would want to select a location where there is plentiful water vapor, and the number of aerosol particles could be increased. A great location is over the ocean where machines can spray seawater through very small nozzles that effectively introduce numerous small sea salt particles into the moist overlying atmosphere. These sea salt aerosols act as cloud condensing nuclei and can brighten low marine clouds. (See PowerPoint for details and illustrations.)*

9. What are some possible limitations and risks to scaling this technology to use in the real-world?

*Some possible limitations to scaling this climate engineering technology are costs, limited ocean areas containing low clouds, low background aerosols, and are far from land to minimize potential negative impacts, necessary global cooperation and support, and marine cloud brightening does not address increasing atmospheric greenhouse gases nor ocean acidification. Some possible risks include regional to global changes in precipitation amounts and patterns, regional changes to atmospheric and ocean chemistry, impacts on biology and ecosystems, and the potential for rapid change if marine cloud brightening is abruptly terminated without alternative solutions in place.*