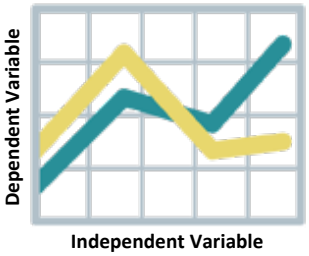
Designing Experiments

Taking the time to design a good experiment is a key component of doing good science! You must carefully think through each aspect of the experiment to make sure that your experiment helps you answer the scientific question that you wish to answer. The following information will help you design your own scientific study using the instrument. It is important to think through each step thoroughly, to make sure that the experiment that you design answers the question you want to answer in an unbiased, scientific way.

Steps to Designing a Scientific Study

1. **Determine which scientific question that you would like to explore using the instrument.**
2. **Formulate a hypothesis.**
   Your hypothesis should be based on what you have learned about particulate matter and aerosols so far. It should be an "educated guess" to answer your scientific question. Your experiment will be designed to disprove your hypothesis, so make sure that your hypothesis is testable.



3. **What are your independent and dependent variables?**
   In your experiment, the independent variable will be the variable that is varied or manipulated by your group, and the dependent variable is the response that is measured.
4. **Variables that need to be controlled.**
   Are there any other variables that you need to control for in your experiment? You need to control any variables that may impact your dependent variable.
   a. How will you control these variables? Sometimes, scientists run a "control experiment" for comparison. Sometimes, there are many variables that might impact the experiment. One good way of handling this situation is to collect the data several times and find an average—that way the other variables are "averaged out."

5. **Design a procedure for your experiment.**
   What steps will you take to test your hypothesis? How will you vary the independent variable and measure your dependent variable? How often will you collect data?
6. **Collect data and record any observations**
7. **Analyze your data**.
   This usually includes doing a statistical analysis, such as finding averages and standard deviations. Standard deviations are usually used in "error bars" in graphs to show how much uncertainty there is in a particular measurement.

Example of Experimental Design

Now that we know the steps in designing an experiment, let's look at an example:

In the city of Farmtown, CA, there are several farms that are next to the Blue River. Sally, Diego, and Monique are environmental researchers that want to examine pollution in the Blue River. Nitrate and phosphate are both chemical substances that are found in the fertilizers used for farming. Sally, Diego, and Monique have an instrument that can measure the concentrations of nitrate and phosphate in water samples. These are the steps they take to design an experiment with this instrument:

1. **Determine a scientific question.**
   The three researchers all have different ideas for scientific questions they can address. Some of their ideas are:
   a. Do the concentrations of nitrate and phosphate in the water change when it rains?
   b. Do the concentrations of nitrate and phosphate in the water change with time after the farmers add fertilizer in the Spring?
   c. Do concentrations of nitrate and phosphate in the water change at different locations along the river that are different distances from the farms?

   After some debate, the researchers decide to explore the first question, (a). Although these questions are all important, practical reasons may be helpful in determining which question to pursue. In this case, it is the rainy season, so it makes the most sense to pursue question (a).
2. **Formulate a hypothesis.**
   After doing some research, the researchers know that fertilizers contain nitrate and phosphate. They also know that rain water can drain into the river. Therefore they form the following hypothesis:

   > *If it rains, the concentrations of nitrate and phosphate in the river will increase.*

3. **Independent and Dependent Variables.**
   The independent variable will be time after it rains, and the dependent variables will be the nitrate concentration and the phosphate concentration.
4. **Variables that need to be controlled.**
   There are some other variables that will need to be controlled. First, the location at which the samples are collected should remain constant. A "control experiment" would include monitoring the nitrate and phosphate concentrations in the river when it is not raining. Lastly, there may be small inconsistencies in the data, so 3 samples should be tested at each time point so the averages can be computed.

5. **Designing a Procedure**
The researchers need to come up with a procedure for their experiment. How would you design a procedure to test this hypothesis?

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After you've thought about how this experiment might be designed, identify the flaw or flaws in each one of these experimental designs:

Procedure 1: The researchers decide to split up the measurements so that none of them have to collect data for more than a few hours. They keep an eye on the weather forecast, and on the day before it starts raining, Sally will go outside at some point, and take three measurements of the nitrate and phosphate concentrations in the river next to her house. The next day, Diego will be in charge of the morning measurements, and will take 3 measurements of the concentrations in the river outside of his school every half hour. Monique will do the afternoon measurements in the same way, in the river outside of the school.

Flaws:_____

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Procedure 2: The researchers keep an eye on the weather forecast, and on a day before its supposed to rain, the researchers will take one measurement of the nitrate and phosphate concentrations in the river outside of Sally's farm. The next day, when it starts raining, the researchers will measure the concentrations of nitrate and phosphate at the same place, taking one measurement every 30 minutes, until it stops raining.

Flaws:_____

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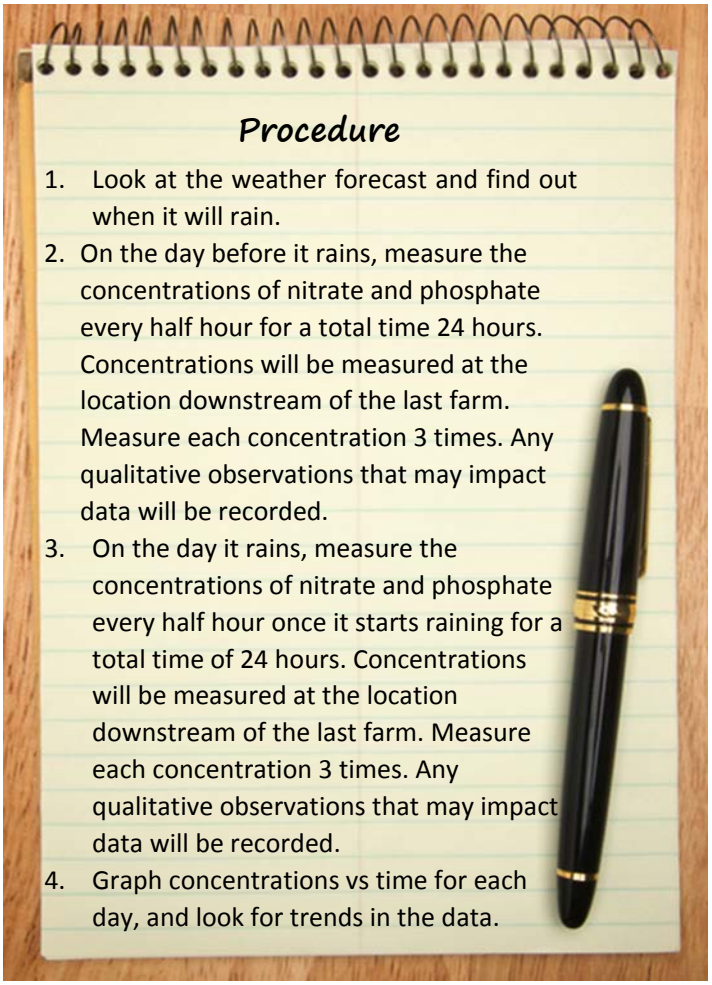
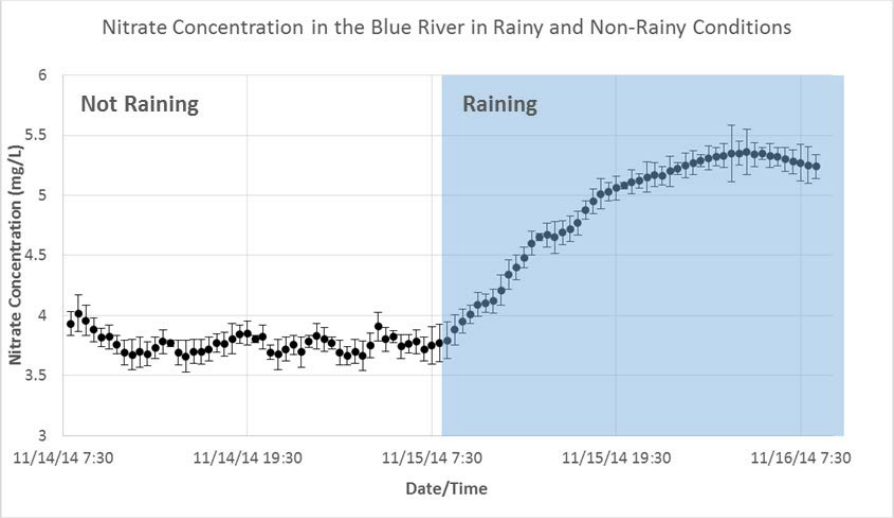
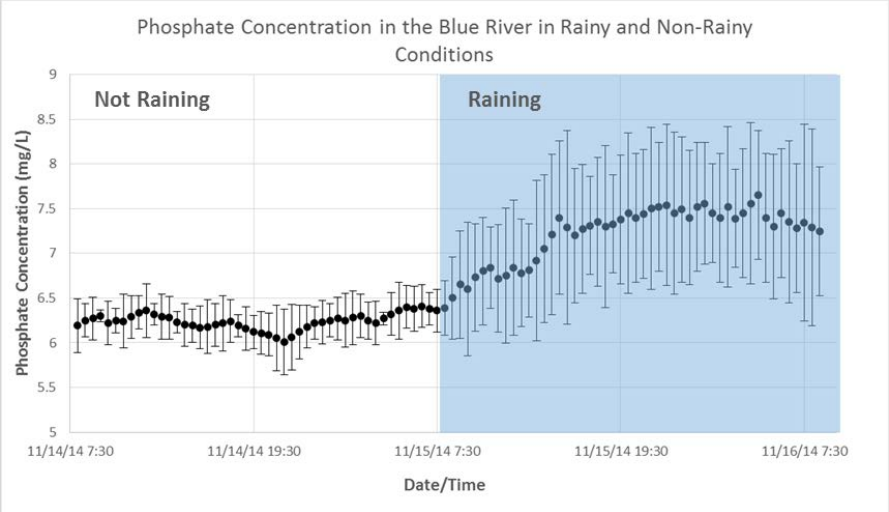
The researchers agree on the following procedure for their experiment:



6. **Data Collection**
   The researchers collect their data according to the procedure. They record their observations about the rain and weather at each time point that they collect data. They record the time it starts raining, which is 8:12 AM on 11/15. It is pouring rain all day, and it starts showering at 5:00 PM (17:00). It stops raining at midnight.
7. **Data Analysis**
   The researchers find the average concentration of both nitrate and phosphate at each time point, and calculate the standard deviation. They graph this data in two graphs, using the standard deviation for the error bars. The graphs are shown on the next page.





These graphs seem to indicate that when it rains, the concentrations of both nitrate and phosphate in the water increase. But what do the error bars indicate? The error bars show how precise a measurement is, which is given by the standard deviation. The nitrate measurements have small error bars, and therefore the researchers can conclude that nitrate concentrations increase when it starts raining. However, the phosphate measurements have large error bars, and the size of the error bars increases for higher concentrations. Because there is so much uncertainty in these measurements, the researchers can't say for sure based on this experiment that the phosphate concentrations increase when it rains.

Designing your own research project with the CLEAR-Case

For your research project, you will be working as part of a research group. It is very common in scientific research to work in teams, allowing for the generation of many ideas. In this activity, you will be working in your research group to design an experiment with the CLEAR-CAICE. Some people in your group may have some ideas for a scientific question to explore—work off of their ideas, and come to a consensus for what question you will address. Discuss how you will address this question, using the steps outlined above. Then, you will prepare your ***Scientific Proposal*** using the attached worksheet.

Scientific Proposal

Scientific Question:

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Research/Background: What information can you find in this packet or online that will help you come up with an educated guess for your hypothesis?

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Hypothesis:

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Variables:

Independent Variable:_____

Dependent Variables:_____

Variables to be controlled:_____

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Procedure: