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Using temperature and light data loggers to drive an inquiry-based environmental science field lab

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Engineering design principles were applied to the development of a modular, inquiry-based introductory (100-level) environmental science lab. Engineering design focuses around addressing a problem through an iterative process that acknowledges constraints in the system and optimizes the outcome for success. The laboratory exercise was designed for students to work through the process of designing an experiment, given realistic constraints of the system. While the research question they asked was relevant contextually, the lab was not focused on the merit of the question students developed. Learning goals were focused on 1) developing a testable question and appropriate experimental design; 2) collecting data, organizing data, and applying an appropriate data analysis methodology; 3) reflecting on the experimental design and system constraints to address the research question. Each group of students were provided with two temperature and light data loggers and then assigned the problem of designing an effective experiment that addressed a novel environmental science question of interest to the students. Students were asked to consider the following in their experimental design: 1) treatments tested; 2) frequency of sampling; 3) replication. One focus of this lab was for students to critically reflect on the design process and use an iterative approach to refine their experimental design. Following data collection in the field for one week, students were tasked with summarizing their data in a meaningful way, to help evaluate the effectiveness of their experimental design. At the end of this modular lab, students reflected on what aspects of their experimental design worked, limitations in their experimental design, and major constraints encountered.

Keywords: temperature, light, environmental science, inquiry-based learning

Introduction

This lab exercise was designed as a three-part modular lab for three 3-hour labs. The lab exercise can be scaled down for use as a single lab or for shorter time period labs. Although used in a 100-level introductory environmental science lab, this exercise can be applied for an upper division course or other disciplines. This lab will allow students to be vested in the development and design of a novel scientific experiment. The focus of this lab exercise is on the process of designing and implementing a scientific experiment, given multiple constraints in the system. Students should be challenged to work through the process of designing an experiment, which may not work on the first iteration due to unknown real-world limitations.

Students will gain experience setting up, deploying, and retrieving data from a data logger, based on a question of interest. Results will vary, based on the research question addressed. Students who use this lab will take away: 1) a novel research question that can be further developed over time; 2) environmental temperature and

light data that can be used to generate a graph; 3) a series of questions to guide reflection on the process of designing an experiment with logistical constraints.

This workshop will involve laboratory and field work. Students will begin by working in the lab to develop a question of interest, an appropriate experimental design, and then set up their data loggers for deployment in the field. Any open area, such as a lawn, landscaped habitat, or natural habit will work for deployment of the data logger. Data will be collected in the field for a defined period, before returning back to the lab to download the data, analyze the data, and reflect on the experimental design process.

If data loggers are not available, historical temperature and precipitation data from monitoring stations across the United States, through the Climate Explorer website (https://crt-climate-explorer.nemac.org/), can be substituted.

Student Outline

Objectives

Develop a testable question and appropriate experimental design
Collect data, organize data, and apply an appropriate data analysis methodology
Reflect on the experimental design and system constraints to address the research question

Introduction

During the next three weeks, we will focus on the development of a testable question, design of an appropriate experiment, deployment of temperature and light intensity data loggers to test a question of interest, data analysis, and assessment of the experiment you designed.

Scientists often use data loggers to record changes in environmental data over time, in an effort to address a contextually relevant research question more efficiently. You could collect the same data by having multiple people visit multiple field sites and spend hours, days, or weeks recording data. A data logger allows the scientist to record data in multiple sites simultaneously and remotely. The data is saved internally in the device and can be downloaded to a smartphone in the field. You will have access to data loggers that can measure temperature and light intensity.

Methods and Data Collection

Part 1: Development a question of interest and an appropriate experimental design

Work in groups to develop a research question that is of interest to you. For example, you might want to ask (and test) how soil temperature varies in two relevant habitats, based on an observation you made in the field. At this point, you are conducting novel environmental science research to address a question that has not been tested, which is very exciting. Be creative and think about what interests you and what you are curious about. Bounce ideas off each other and your lab instructor. While your lab instructor cannot tell you what question to address, they can direct you toward a question that is feasible. You will need to work within the constraints of equipment and material available, which will pose challenges that you will have to address. Each group will have two data loggers that can record temperature and light intensity over time.

Once you have developed a question of interest, develop an appropriate experimental design to test that question. You will need to consider: 1) treatments being tested; 2) frequency of sampling; and 3) replication. Additionally, you will want to decide if you will need to collect any other data to help address your question. Your lab instructor can let you know if specific equipment is available.

The best research questions and methodology for experimental testing are “simple yet elegant”. In other words, do not over complicate a simple question. Good experiments involve treatment(s) and control(s). A treatment includes a variable(s), which is what you want to measure or manipulate. A control is used to serve as a comparison point with the treatment(s). The testing of soil temperature between two field sites (i.e., forested and cleared) would be an example of a treatment with two levels. In this case, a control is not needed, since you are making relative comparisons between the two levels in your treatment. Your variable would be soil temperature.

Scale and frequency of data collection are one item to consider when using a data logger. The frequency of recording a data point needs to be appropriate to the question being tested and the signal you want to capture.

For example, if you were testing how temperature changes at two field sites over the course of a day, you may want to record data every 10 minutes. If you recorded data every second, you will be recording at a rate that is not appropriate to the scale of your question and you may run out of memory in your data logger. If you recorded data every hour, you may miss changes in temperature that help you to address the question that you are asking.

All good experiments involve replication. This means that you want to test your hypothesis on more than one object or individual to be more confident that your results are representative of the entire population being sampled or surveyed. For example, if you used only one data logger to collect temperature data in one location over the course of one day, would you feel confident that the data collected was representative of temperature for every similar site, over every day? In this lab, you will need to think about how you will include replication in your experimental design, given the constraints of available equipment. As you design your experiment, keep in mind that a minimum of three replicates are needed for most statistical analyses, including calculating an average.

Part of the process of designing a good experiment is critically evaluating your design and making changes. Use a SWOT (Strengths, Weakness, Opportunities, and Threats) analysis to help you critically think about potential improvements to your experimental design and to raise awareness about potential problems you may encounter. Strengths and Weaknesses are internal and controllable. Opportunities and Threats are external and difficult to control.

- **Strengths:** Strength of your experimental design. For example, what skill, resources, or attributes will positively add to the success of your experiment.
- **Weaknesses:** Limitations or constraints in the experiment that you are designing
- **Opportunities:** Factors that may contribute to the success of your experiment
- **Threats:** Factors that may negatively impact your experiment. For example, what poses a risk to the success of your experiment.

Begin by spending 10 minutes to develop a SWOT analysis independently. Then discuss each lab group member's analysis and come to a consensus. As a group, look at your strengths to see if you can address any of the weaknesses that you identified in your experimental design. Can your strengths take advantage of your opportunities to address any threats?

In advance of next week's lab, you may want to download the "HOBOconnect" app on your smartphone or tablet, which will be used to set up and download data from your loggers. The software is free and can be downloaded on the App Store or Google Play, depending on your device. As you are developing your experimental design, you are welcome and encouraged to examine the data loggers.

Submit your question, experimental design, and expected outcome before you leave the lab; one submission per lab group is fine. A summary of your experimental design and expected outcome should be concise. Be sure to clearly state your question. In the summary of your experimental design, clearly state how you will test your question, which should include treatments being tested, frequency of sampling, and how you will address replication. Include a list of all members in your group.

Part 2: Deployment of data loggers and collection of additional data

In lab this week, you will configure your data loggers, turn them on (i.e., start logging), deploy your loggers in the field, and collect any additional data that is needed to address your question.

Review your experimental design and "game plan" with your lab partners. Discuss with your lab partners and lab instructor, if needed, any modifications to your experimental design.

Download the "HOBOconnect" app on your smartphone or tablet, which will be used to set up and download data from your loggers. The software is free and can be downloaded on the App Store or Google Play, depending on your device.

Open the software on your device.

- Tap "Settings" on the bottom menu and set units to "SI". You only need to do this once.

- Make sure your device's Bluetooth is turned on.
  For each logger, do the following:
- Tap "HOBOs" on the bottom menu
- Wake up your logger by firmly pressing the button in the center of the logger. A red and green LED should flash. Your logger should be listed in the "Recently Seen/In Range" box at the top of your screen.
- Connect to the logger by tapping on the logger listed in "Recently Seen/In Range".
- Tap on "Configure" to set up your logger
- Most of the settings can be left as the default settings. Below are a few settings that you can or will need to change:
  - **Name:** You can enter a name if that will help you identify the logger
  - **Logging Interval:** Set the logging interval to the appropriate frequency, based on your question addressed and experimental design

  The following settings should **not** be changed and left as default:
- **Start logging:** Keep set as "now"
- **Stop logging:** Keep set as "when memory fills"
- **Temperature and Light intensity alarms:** Keep set as on and do not change settings
- **Logging mode:** Keep set as "normal"
- **Show LED:** Keep set as "on"
- **Bluetooth always off:** Keep set as "on"

After you set up your logger, tap on "Start" in the upper right corner to launch your logger. You should receive a notification that your logger has been configured successfully.

Confirm that your logger is configured and logging by checking the logger display at the top of your screen. You should see "Configured, Logging", if you have configured and started logging. You can also tap on "Full Status Details" > "Current Configuration" to double check your configuration settings, such as logging interval.

Please <u>do not</u> set a password for your logger.

Deploy your logger in the field. Based on your experimental design, please make sure that you have securely attached your logger, so it can be recovered next week. Be sure to record the location of your logger and mark if needed, so it can be recovered. Since your logger is recording data, you will want to note the time that you have the logger fully deployed, so you can ignore data that was recorded before you finished deploying your logger.

Collect any additional data, if needed, based on your experimental design.

Next week you will retrieve your data loggers, download data, and begin to analyze your data.

This assignment should be submitted independently (i.e., **not** as a group). In 1-2 pages, double spaced 12 pt font, please concisely address the following points:

- Summarize the constraints that you encountered as you were designing your experiment
- Describe significant changes that you made to your initial experimental design, compared to the final version prior to deployment of your loggers
- Frequently, what you conceive during the planning phase is different in comparison to what you were able to do in the field (i.e., placement of loggers or other aspects may need to be adjusted). Describe any changes that you had to make or challenges that you encountered when you deployed your data loggers in the field.
- Indicate what you think are some potential problems that you may encounter when you retrieve your loggers and download your data.

Part 3: Retrieval of data loggers and analysis of data

In lab this week you will retrieve your data loggers, download data collected, and begin to analyze your data. Data analysis will involve organizing and structuring your data in a way that you can remember what the data means in the future, summarizing results (i.e., mean values and variation) and generating graphs. As you delve into

your data, keep in mind that one objective was to work through the process of designing an experiment to address a question of interest. Try not to get bogged down in how to analyze or interpret your data. Think about the process of data collection with regards to what worked, what did not work, and what would be changed if you repeated this experiment to test your research question.

You will need to think about how to summarize your data in a meaningful way, to help you evaluate the effectiveness of your experimental design. One way to summarize replicated data is to calculate a mean value (average) for all your replicates. Since each replicate data point is not exactly the mean, a measure of variation can be used to describe the level of variation your data has around the mean value. A standard deviation is one metric that can be used to represent variation.

Go out into the field and collect your data loggers. Record the time that you remove your data loggers, so you will know which data points are no longer valid. Be sure to bring back all equipment used in the field.

Record any interesting or unique observations that may help you interpret your data.

In the lab, open up the “HOBOconnect” software on your device and wake up your logger by firmly pressing the button in the center of the logger.

- Connect to the logger by tapping on the logger listed in “Recently Seen/In Range”.
- Tap on “Readout” to download data to your mobile device
- In the bottom menu, tap on “Data Files”. Tap “Yes” to close the connection with your logger.
- A graph showing your data will be visible. Tap on the graph. At the top of the screen, Tap on the “Share As...” button (square with an up arrow). Export your data as an “XLSX Excel file” and tap on “Share File”. You can email the file to yourself and your labmates.
  Rename your file with a name that will allow you to identify the file for future use.
- Repeat this process for your second logger, making sure to clearly rename the data file

Open both data files in Excel. You will see three tabs labeled Data, Event data, and Details. The Event Data and Details tabs contain information about the logger and operations, which you most likely will not need to use. The Data tab will contain your data in three columns: Date/Time, Temperature, and Light. If you did not address a question about temperature or light, you can ignore that column.

Copy and paste your data from both loggers into the Environmental Data spreadsheet template that is provided. A column for site (the level of treatment that you collected data at) and replicate number are added. **Past date/time data, temperature, and/or light data into the appropriate columns.**

You can change the formatting of the day/time data by highlighting the cell(s), clicking on Format Cells > Number > Custom. The default formatting for your data is “yyyy-mm-dd hh:mm:ss”. You can remove the date, if you want or remove the seconds, if they are not needed, or other modifications by changing the text in the box. For example, “yyyy-mm-dd hh:mm" would not display seconds and “hh:mm" would only display time with no seconds.

Review your notes and delete any data that was recorded before you deployed your logger in the field and any data that was recorded after you removed your logger from the field.

Enter a name for the site your loggers were placed in, which describes the treatment level (i.e., “field” and “forest”).

Enter a replicate number that indicates which data are considered replicates. This will be based on your experimental design. You will need a minimum number of three replicates. **Ask your lab instructor for help if you are not sure how to determine replication.**

You may have to decide on how to align time between your two loggers, since you did not start them at the exact same time. For example, a data point at 10:30 on logger 1 and a data point at 10:34 on logger 2 could be considered equivalent times.

Since you have three or more replicates, you can calculate a mean (average) value and a measure of variation (standard deviation) for each replicated time point. In other words, if you collected data every 10 minutes, you would have replicate data for each 10-minute interval.

Calculate a mean (average) value and a measure of variation (standard deviation). Excel can do the calculations for you with the following formulas: replace *cells* with cell number range (e.g., A1:A5):

Mean: =Average(*cells*)

Standard deviation: =Stdev(*cells*)

Begin to interpret your data. Often the best starting point is to visualize your data in a graph that shows mean values and a measure of variation in the form of an error bar. You can use any software that you are comfortable with to visualize your data. Ask your lab instructor for suggestions or help if you are not sure how to graph your data. Think about the following:

Did the data you collect answer your question?

What was the importance of the data you collected?

If you ended up with any surprising results, what do the results tell you?

This assignment should be submitted independently (i.e., **not** as a group). In 1-2 pages, double spaced 12 pt font, please concisely address the following points:

- Reflect on what worked and what did not work. What would you do differently if you repeated this experiment?
- Discuss what were the major constraints in your experimental work?
- Address whether you were able to effectively address the question you asked with data you collected and explain why?
- Concisely summarize one key finding from your experiment

Materials

HOBO Pendant MX Temperature/Light data loggers (MX2202) from Onset Computer Corporation were used to collect data. A minimum of two loggers per student were used. Students were responsible for supplying a mobile device. The HOBOconnect app, which is used to access data loggers from a mobile device, is free to download from https://www.onsetcomp.com/products/software/hoboconnect/. Two-inch PCV pipe can be used as a solar radiation shield, if needed.

Notes for the Instructor

Some students may struggle with the challenge of developing a testable research question. Allowing students to visit a field site, prior to the start of this lab will help students to familiarize with the ecosystem and will help to start the process of generating a research question. The instructor should avoid giving students a question to address.

Technical issues may arise when students try to connect their mobile devices to the data logger. Check for updates to the HOBOconnect app or the release of new apps prior to the start of lab.

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About the Author

Michael Berger has been an Associate Professor (career-track) at Washington State University since 2008.

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