Exploration: Sand crabs

Section 1.1 Learning Goals:

- Distinguish experiments and observational studies
- Review basic study design principles such as inclusion criteria and random assignment
- Define terminology specific to an experimental study (e.g., treatments, factors)
- Produce a Sources of Variation diagram for an experiment
- Apply the six-step investigative process

Sand crabs are small crabs that spend most of their time buried in sand. After waves wash the sand crabs onto the beach, the faster they can bury themselves the more quickly they are protected from shore bird predators. To explore the effects of the moisture level of the sand (dry, medium, wet) on burying time, a Biology graduate student (Saniee, 2018) acquired sand crabs from a California beach by going to the shallow parts of the beach and digging down about one inch of sand below the crab without disturbing the crab. These sand crabs were kept in a large bucket that was transported back to the lab filled with the sand that was dug up around them and water, so they could stay buried until the time of the experiment. Each crab was randomly assigned to a moisture level, and then transferred to a new container of sand with this moisture level. The time (in seconds) each crab took to completely bury itself in the sand was recorded. The same protocol was followed for all crabs.

Definition: The ***study protocol*** outlines how the study will be conducted, providing enough detail, so that someone else could carry out the same study under identical conditions. It is important to consider the research question when evaluating whether the study protocol will be appropriate.

STEP 1: Ask a research question.

1. What was the *research question* for conducting this study?

STEP 2: Design a study and collect data.

2. Identify the *response variable*. Is this variable quantitative or categorical? (If categorical, note the number of categories. If quantitative variable, note the measurement units.)

3. Was this an *observational study* or an *experiment*? How are you deciding? (*Hint*: Recall that the key characteristic of an experiment is that the researcher determines which treatment group each participant is in.)

Definition: The explanatory variable deliberately manipulated in an experiment is often called a ***treatment variable*** or ***factor***. For categorical explanatory variables, the different categories of the treatment variable are often called ***levels***. In experiments, the objects (or "subjects") that we are measuring are often called ***experimental units***. The conditions we impose on the experimental units (here the levels of the treatment variable) are also called ***treatments.*** Each experimental unit is assigned to one treatment.

4. Identify the *experimental units* in this study. How many are there?

5. Identify the *treatment variable* and its *levels*. Also identify the *treatments*.

6. Complete the Sources of Variation diagram, including brainstorming some possible sources of unexplained variation.

Observed Variation in:	**Sources of explained variation**	**Sources of unexplained variation**
Inclusion criteria: *Design:*		

7. If you were planning this study, how would you determine which crabs gets which treatments? What would you be trying to accomplish?

Key Idea: The goal of *random assignment* is to reduce the chances of there being any association between the treatment variable and any other variable by creating groups that are expected to be as similar as possible (other than the treatment variable of interest). A key consequence of not having any variables associated with the treatment variable in a randomized experiment is the potential to draw cause-and-effect conclusions between the treatment variable and the response variable.

8. Identify any other precautions that were or could have been taken in this study to try to make sure the two treatment groups were as similar as possible, aside from the treatment imposed.

Definition: A study can be described as ***double masked*** (sometimes referred to as double blind) if
(i) the subjects do not know which treatment condition they are in, and,
(ii) the person evaluating the response variable does not know which treatment condition the subject is in.
If only one of the above conditions is true for a study, then the study can be described as ***single masked***.

9. Was this a *double masked* or a *single masked* study? Explain.

10. Are you willing to consider the crabs in this study as *randomly selected*? Do you think the crabs in the study are representative of a larger population of sand crabs? What would you define that population to be?

11. Before we look at the data, in what situation(s) would you suggest excluding any crabs from this study? Explain.

Definition: ***Inclusion criteria*** are the set of characteristics that individuals must have in order to participate in a study.

Key Idea: Using inclusion criteria may reduce the variation in the observed response compared to what would otherwise be observed if there were no inclusion criteria. However, by using inclusion criteria we limit the scope of inference for study conclusions. The more inclusion criteria there are, the smaller the population to which the study conclusions will apply.

STEP 3: Explore the data.

Open the ***sandcrabs*** data and select the 3 columns. In the **Multiple Variables** applet, press **Clear** to clear the existing data and then paste in the three columns of data into the data box, press **Use Data**. Drag the *BuryTime(s)* variable into the Response box. Check the **Show descriptive** box.

12. Based on the displayed numerical and graphical summaries of the outcomes of the response variable, summarize your observations on shape, center, and variability of the distribution.

Key idea: A ***statistical model*** is an equation that predicts the outcome of the response and measures the accuracy of those predictions.

13. Specify a statistical model for predicting future burying time results using the overall mean time for the available sample and specifying the standard deviation of the bury times. (Sometimes referred to as the "single mean" model.)

Drag the *SandType* variable into the **Subset By** box.

14. This creates numerical and graphical summaries comparing the results for the three treatment groups. Based on the group means, did one of the moisture level groups tend to have faster or slower burying times than the others? By a lot or just a little? Which group had more variable results? How are you deciding?

15. Write out a statistical model for predicting burying time outcomes depending on which treatment condition a crab is assigned to, using the treatment-specific mean times. This could be called the "moisture level model" or the "separate means model." **Note**: The "separate means model" allows us to assign a predicted response, the group mean, for each treatment in contrast with the "single mean model" which uses the same overall mean response to make our predictions regardless of treatment.

Check the **Show Residuals** box.

16. Is the standard error of the residuals for the moisture level grouping model much smaller than the standard deviation of the responses in #13 (equivalent to the standard error of the residuals in the single mean model)?

17. Does knowing which treatment group each crab was assigned to explain all of the variation in the responses? How are you deciding?

STEP 4: Draw inferences beyond the data.

This step entails investigating whether the observed difference in average times between the three treatment groups reflects a genuine tendency, and if so, estimating the size of the tendencies. We will look at Step 4 in detail at a later time. For now, let's move on to Step 5. In this step, we need to review the study protocol to determine the "scope of conclusions" we can draw from the study.

STEP 5: Formulate conclusions.

18. Recall the Sources of Variation diagram you filled out in #6 that listed possible sources of unexplained variation. One potential source of variation in how quickly a sand crab buries itself is the sex of the sand crab (male or female) because male sand crabs tend to be smaller than female sand crabs. Ideally, the study protocol has balanced this variable among the treatment groups (i.e., there is a similar mix of male and female sand crabs in all three treatment groups), but let's check.

Remove the *BuryTimes(s)* variable from the Response box and instead move the *sex* variable there.

19. Does there appear to be an association between moisture level of sand and sex of sand crab? How are you deciding?

20. Earlier you saw some differences in burying times across the three sand types. Based on what you saw in #19, could the sex of the crab be an alternative explanation for the difference in the mean burying time across the three sand moisture types?

Hopefully you found above that there appears to be no association between the sex of the crab and which treatment they received, preventing sex of crab from being a confounding variable. With random assignment, we will often trust that this balance is true for all other potential confounding variables as well.

Key Idea: *Random assignment* is a critical component of a well-designed experiment that allows us to potentially draw *cause-and-effect* conclusions. How the experimental units are selected for the study (e.g., inclusion criteria, *random sampling*) is a key component of how broadly we can *generalize* the results.

21. In summary, to make predictions about much time a sand crab will take to completely bury itself, do you recommend the "single mean" model or the "moisture level" model? Explain. How accurate is the moisture level (or separate means) model? Does the difference in group means seem of practical significance to you in this context? Explain. To what population are you willing to generalize these observations? Are you willing to draw a cause-and-effect conclusion between the moisture level of sand and time taken to bury completely in sand by sand crabs in this population? Explain.

STEP 6: Look back and ahead.

22. Suggest at least one way you would improve this study if you were to carry it out yourself.