Lesson 28: Drawing a Conclusion from an Experiment

Student Outcomes

- Students carry out a statistical experiment to compare two treatments.
- Given data from a statistical experiment with two treatments, students create a randomization distribution.
- Students use a randomization distribution to determine if there is a significant difference between two treatments.

Lesson Notes

In these next two lessons, students will participate in the capstone experience of conducting all phases of an experiment: collecting data, creating a randomization distribution based on these data, determining if there is a significant difference in treatment effects, and reporting their findings. The first of these two lessons deals with executing the experiment, collecting the data, and coming to a conclusion via a randomization test. The subsequent lesson asks students to develop a comprehensive report.

As mentioned in the student material, the following experiments are in homage to George E. P. Box, a statistician who worked extensively in the areas of quality control, design of experiments, and other topics. He earned the honor of Fellow of the Royal Society during his career and is a former president of the American Statistical Association. Several resources are available regarding his work and life including the book *Statistics for Experimenters: Design, Innovation, and Discovery* by Box, Hunter, and Hunter. There is other material written by and about him that would be accessible to secondary school students interested in learning more.

Box would use paper helicopters in some of his classes to provide students with a tangible (and low cost) experience with experimental design and analysis. The experiments in this lesson will investigate if modifications in certain dimensions of a paper helicopter will affect its flight time. A blueprint and construction notes appear at the end of the student lesson. You might want to practice making and flying a few of these helicopters in the days leading up to the lesson. Students are advised that they may want to use a piece of tape to secure the two folded body panels to the body of the helicopter for greater stability. By design, there will be some overlap from this folding in some helicopters.

Classwork

At the start of the lesson, ask students to restate to a partner or in writing the important parts of experimental design they have learned.

First, read through the opening text with students and briefly summarize the experiment. Then, allow students to work on the exercises with a partner or in a small group.

While the students' data will vary, generally speaking,

- The helicopters with longer wings should stay in flight longer, on average, than the helicopters with shorter wings.
- The helicopters with wider bodies (this variable is explored in the problem set) should have an average flight time that is significantly less than the average flight time of the helicopters with narrower bodies.

Scaffolding:

- Consider showing a visual, such as a poster with all directions, to help describe the experiment.
- Ask students to restate the directions either verbally or by writing them.

Two key points before starting:

- If students discover a significant difference in any of the experiments, they should be careful NOT to over-generalize or extrapolate their findings. For example, observed differences may or may not occur with larger helicopters or helicopters made of different material. Moreover, students should not assume that the significant difference in average flight time observed by a longer wing length of 1 inch would necessarily be doubled (or even occur at all) if the wing length were increased by 2 inches, for example.
- Encourage students to minimize potentially confounding factors that could distort the data collection. For example, find an environment that is as windless as possible, use the same type of paper for all helicopters, drop them all from the same height, and so on. Also, have students randomize the order in which they drop the first 30 helicopters so that any peculiar, unforeseen, or unknown factors that may affect flight times is distributed among the groups and not necessarily localized to any one group.

This lesson does require the use of scissors, tape, a stopwatch, a ruler, and, possibly, a measuring tape.

> **In this lesson, you will be conducting all phases of an experiment: collecting data, creating a randomization distribution based on these data, and determining if there is a significant difference in treatment effects. In the next lesson, you will develop a report of your findings.**
>
> **The following experiments are in homage to George E. P. Box, a famous statistician who worked extensively in the areas of quality control, design of experiments, and other topics. He earned the honor of Fellow of the Royal Society during his career and is a former president of the American Statistical Association. Several resources are available regarding his work and life including the book *Statistics for Experimenters: Design, Innovation, and Discovery* by Box, Hunter, and Hunter.**
>
> **The experiments will investigate whether modifications in certain dimensions of a paper helicopter will affect its flight time.**

Exercise 1 (5 minutes): Build the Helicopters

This task may be performed in advance of the day of data collection. Also, it is strongly recommended that multiple copies of the original helicopter blueprint be available. Consider posing the following question to the class and allow for multiple responses:

- What are some statistical questions you would want to answer about helicopters?

> **Exercise 1: Build the Helicopters**
>
> **In preparation for your data collection, you will need to construct 20 paper helicopters following the blueprint given at the end of this lesson. For consistency, use the same type of paper for each helicopter. For greater stability, you may want to use a piece of tape to secure the two folded body panels to the body of the helicopter. By design, there will be some overlap from this folding in some helicopters.**
>
> **You will carry out an experiment to investigate the effect of wing length on flight time.**

Scaffolding:

- According to the needs of your students, consider making the experimental design and execution as unstructured as possible. Give students an opportunity to design an effective experiment as independently as possible. Consider using each exercise as a task that students should complete and use to assess their progress in the experiment.

a. **Construct 20 helicopters with wing length $=$ 4 inches, body length $=$ 3 inches. Label 10 each of these helicopters with the word "long."**

b. **Take the other 10 helicopters and cut one inch off each of the wings so that you have 10 helicopters with 3 inch wings. Label each of these helicopters with the word "short."**

c. **How do you think wing length will affect flight time? Explain your answer.**

Answers will vary. I think that a longer wing length will produce more resistance to the air which will result in a longer flight time

Exploratory Challenge 1 (15 minutes): Data Collection

From a consistent height (preferably 12 feet or higher), drop each of the 20 helicopters one at a time in a random order. Record the time it takes for each helicopter to reach the ground. Encourage students to record any relevant comments such as "this group's helicopters had a smoother flight" and so on.

Exploratory Challenge 1: Data Collection

Once you have built the 20 helicopters, each of them will be "flown" by dropping the helicopter from a fixed distance above the ground (preferably 12 feet or higher—record this height for use when presenting your findings later). For consistency, drop all helicopters from the same height each time, and try to perform this exercise in a space where possible confounding factors such as wind gusts and drafts from heating and air conditioning are eliminated.

a. **Place the 20 helicopters in a bag, shake the bag, and randomly pull out one helicopter. Drop the helicopter from the starting height, and, using a stopwatch, record the amount of time it takes until the helicopter reaches the ground. Write down this "flight time" in the appropriate column in the table below. Repeat for the remaining 19 helicopters.**

Some helicopters might fly more smoothly than others; you may want to record relevant comments in your report. ***Answers will vary.***

Flight Time (seconds)

Long Wings (Group A)	Short Wings (Group B)

b. **Why might it be important to randomize (impartially select) the order in which the helicopters were dropped?**

(This is *different from* the randomization you perform later when you are allocating observations to groups to develop the randomization distribution.)

Randomizing the order in which the 20 helicopters are dropped will allow any peculiar, unforeseen, or unknown factors that may affect flight times to be distributed among the groups and not necessarily be localized to any one group.

Exploratory Challenge 2 (15 minutes): Developing Claims and Using Technology

Exploratory Challenge 2: Developing Claims and Using Technology

With the data in hand, you will now perform your analysis regarding the effect of "wing length."

Experiment: Wing Length

MP.3

In this experiment, you'll examine whether wing length makes a difference in flight time. You will compare the helicopters with long wings (wing length $= 4$ inches, Group A) to the helicopters with short wings (wing length $= 3$ inches, Group B). Since you are dropping the helicopters from the same height in the same location, using the same type of paper, the only difference in the two groups will be the different wing lengths.

Questions: Does a 1-inch addition in wing length appear to result in a change in average flight time? If so, do helicopters with longer wing length or shorter wing length tend to have longer flight times on average?

MP.5

Carry out a complete randomization test to answer these questions. Show all 5 steps and use the "Anova Shuffle" Applet described in the previous lessons to assist both in creating the distribution and with your computations. Be sure to write a final conclusion that clearly answers the questions in context.

Step 1—Null Hypothesis: A 1-inch increase in wing length does not change average flight time.

Alternative Hypothesis: A 1-inch increase in wing length changes average flight time.

Step 2— Students will compute "Diff" from the experiment's data. The value WILL most likely be statistically significant.

Step 3—Randomization Distribution of "Diff" developed by student using applet.

Step 4—Compute the probability of obtaining a "Diff" more extreme than the value from the experiment. Since the original question is asking about a "change" in flight times (as opposed to a strict "increase" or "decrease"), the alternative hypothesis is of the form "different from," and students should select the "beyond" choice from the applet under "Count Samples."

Step 5—While there is no specific criteria stated in the question for what is a "small probability," students should consider probability values from previous work in determining "small" vs. "not small." Again, student values will vary. The important point is that the students' conclusions should be consistent with the probability value and their assessment of that value as follows:

- *If students deem the probability to be "small," then they should state a conclusion based on a statistically significant result. More specifically, we support the claim that a 1-inch increase in wing length changes average flight time. Given the sign of the observed difference and the method students have chosen for computing "Diff" (e.g., was it Group A's mean − Group B's mean?), they should state as to whether the 1-inch increase in wing length appears to increase or decrease the average flight time.*
- *If students deem the probability to be NOT "small," then they should state a conclusion based on a result that is NOT statistically significant. More specifically, we DO NOT have evidence to support the claim that a 1-inch increase in wing length changes average flight time.*

The expectation is that the helicopters with longer wings should <u>stay in flight longer</u> on average than the helicopters with shorter wings.

Closing (5 minutes)

- What other characteristics of the helicopter could you modify to perform further experiments in flight times?
  - *Sample response: body length, wing width, "middle body" width, material used, and others*
- Ask students to summarize the main ideas of the lesson in writing or with a neighbor. Use this as an opportunity to informally assess comprehension of the lesson. The Lesson Summary below offers some important ideas that should be included.

> **Lesson Summary**
>
> **In previous lessons, you learned how to carry out a randomization test to decide if there was a statistically significant difference between two groups in an experiment. Throughout these previous lessons, certain aspects of proper experimental design were discussed. In this lesson, you were able to carry out a complete experiment and collect your own data. When an experiment is developed, you must be careful to minimize confounding effects that may compromise or invalidate findings. When possible, the treatment groups should be created so that the only distinction between the groups in the experiment is the treatment imposed.**

Exit Ticket (5 minutes)

Name ____ Date ____________________

Lesson 28: Drawing a Conclusion from an Experiment

Exit Ticket

Explain why you constructed a randomization distribution in order to decide if wing length has an effect on flight time.

Exit Ticket Sample Solutions

Explain why you constructed a randomization distribution in order to decide if wing length has an effect on flight time.

There is variability in flight times even for helicopters that have the same wing length. This means that two groups of helicopters with the same wing lengths will still have different mean flight times. So, when we see a difference in the mean flight time for short wing helicopters and long wing helicopters, we need to know if that difference is bigger than the kind of differences we would see just by chance when there is no difference in wing length. This is how we can tell if our observed difference between the flight times of long and short winged helicopters is significant enough that we don't think it is just due to chance.

Problem Set Sample Solutions

One other variable that can be adjusted in the paper helicopters is "body width." See the blueprints for details.

1. **Construct 10 helicopters using the blueprint from the lesson. Label each helicopter with the word "narrow."**
2. **Develop a blueprint for a helicopter that is identical to the helicopter of the blueprint used in class except for the fact that the body width will now be 1.75 inches.**
3. **Use the blueprint to construct 10 of these new helicopters, and label each of these helicopters with the word "wide."**
4. **Place the 20 helicopters in a bag, shake the bag, and randomly pull out one helicopter. Drop the helicopter from the starting height, and, using a stopwatch, record the amount of time it takes until the helicopter reaches the ground. Write down this "flight time" in the appropriate column in the table below. Repeat for the remaining 19 helicopters.**

Flight Time (seconds)

Narrow Body (Group C)	Wide Body (Group D)

5. **Question: Does a 0.5 inch addition in body width appear to result in a change in average flight time? If so, do helicopters with wider body width (Group D) or narrower body width (Group C) tend to have longer flight times on average? Carry out a complete randomization test to answer these questions. Show all 5 steps and use the "Anova Shuffle" Applet described in previous lessons to assist both in creating the distribution and with your computations. Be sure to write a final conclusion that clearly answers the questions in context.**

Once the 20 helicopter flight time data are collected…

Step 1—Null Hypothesis: A 0.5 inch addition in body width does not change average flight time.

Alternative Hypothesis: A 0.5 inch addition in body width changes average flight time.

Step 2— Students will compute "Diff" from the experiment's data. The value WILL most likely be statistically significant.

Step 3—Randomization Distribution of "Diff" developed by student using applet.

Step 4—Compute the probability of obtaining a "Diff" more extreme than the value from the experiment. Since the original question is asking about a "change" in flight times (as opposed to a strict "increase" or "decrease"), the alternative hypothesis is of the form "different from," and students should select the "beyond" choice from the applet under "Count Samples."

Step 5—While there is no specific criteria stated in the question for what is a "small probability," students should consider probability values from previous work in determining "small" vs. "not small." Again, student values will vary. The important point is that the students' conclusion should be consistent with the probability value and their assessment of that value as follows:

- ***If students deem the probability to be "small," then they should state a conclusion based on a statistically significant result. More specifically, we support the claim that a 0.5 inch addition in body width changes average flight time. Given the sign of the observed difference and the method students have chosen for computing "Diff" (e.g., was it Group D's mean – Group C's mean?), they should state as to whether the 0.5 inch increase in body width appears to increase or decrease the average flight time.***
- ***If students deem the probability to be NOT "small," then they should state a conclusion based on a result that is NOT statistically significant. More specifically, we DO NOT have evidence to support the claim that a 0.5 inch addition in body width changes average flight time.***

The expectation is that the Group D helicopters (with wider body width) should have an average flight time that is significantly less than the average flight time of the "control" helicopters of Group C.

Appendix: Blueprint