Bears in a Boat

Who can build the best boat? In this lesson, students are challenged to create aluminum foil boats that are then tested by filling them with plastic bears until they sink. The lesson serves as a fun, hands-on way to collect data. The data from two attempts is collected and used to make two class box-and-whisker plots with some surprising results.

Learning Objectives

Students will:

- Determine a five-number summary for data
- Create box-and-whisker plots
- Use box-and-whisker plots to compare sets of data

Materials

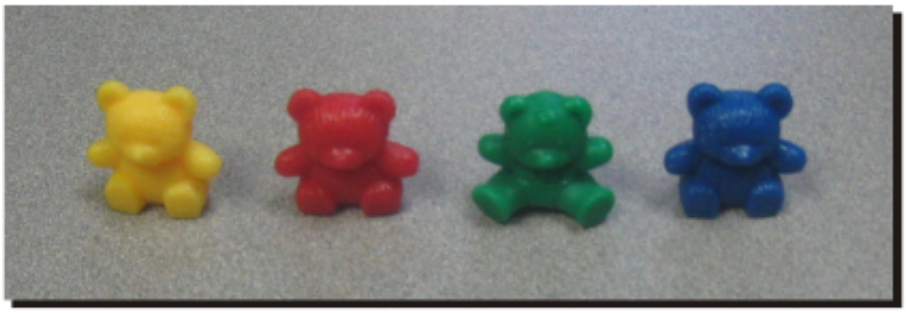
- 6" × 6" squares of heavy duty aluminum foil (four squares per student)
- Four plastic containers, approximately 8" wide, 8" long, and 4" deep
- Hundreds of 4-gram Baby Bears™ plastic teddy bears (about 50 per student)
- Water to fill each container

Instructional Plan

This lesson provides a great introduction to the use of box-and-whisker plots and statistical analysis, but students should have some familiarity with measures of center including mean, median, and range. In addition, this hands-on lesson is great for engaging students, but be aware that **a fair amount of advanced preparation** is required to make this lesson successful. Prior to the lesson, you will need to:

- Fill each plastic container about halfway with water. The water needs to be deep enough so that the aluminum foil boats made by students will eventually sink when filled with bears. The plastic containers must be at least 8" wide, 8" long, and 4" deep, although larger containers work better. (Throughout this lesson, these water-filled containers will be referred to as "lakes." You may wish to label them as Huron, Ontario, Michigan, Erie, and Superior, or with the names of local lakes or rivers in your area.)

- Arrange the lakes throughout the room so that students have ample space to work. It is best to place only one lake on a table.
- Next to each lake, place about 100 bears. (Note that other objects can be used if plastic bears are not available. Unifix cubes or any small plastic items that are uniform in weight and size will work, but the approximate weight of each item should be 3-5 grams.)



- Have an ample supply of clean-up materials, including a sieve (to scoop the bears out of the water), towels to dry the bears, and paper towels to mop up any spills made while students are working.

Distribute one piece of 6" × 6" aluminum foil to each student.

Explain to students that they will use the foil to create a "boat" by folding it in any manner they choose. Warn them not to rip, tear, or make a hole in the foil. If they do, their boat will sink. Tell them that after constructing their boat, it will be floated in a lake and filled with bears. Their goal is to keep the bears afloat (dry); they do not want the boat to sink. Tell them that they will test their boat by placing it in the lake and loading it with bears until it sinks. Show students the lakes and bears around the room.

Divide the class so that there is approximately the same number of students at each lake. One at a time, students should place their boats on the lake and carefully load the boat with bears. A sample boat loaded with bears is shown in the picture below. The students' goal is to get as many bears as possible into their boats. They will quickly learn to balance the load and place the bears carefully. You may be asked, "May I start again?" and it is acceptable to permit that once.

Each student should record the number of bears that their boat was able to hold. The *capacity* of the boat is the number of bears in the boat just before the boat sinks. For example, if the 28th bear placed in a boat caused it to sink, then the capacity of that boat was 27.

Record the capacity of each student's boat. Sort the capacities and place them in a table. It is not unusual to have capacities that range from lows of 9 or 10 to highs greater than 60. The following is a typical sample for a group of 13 students:

Student	Ada	Ben	Cal	Dee	Eve	Fae	Gia	Hal	Isa	Jen	Kay	Lue	Mai
Capacity	10	15	18	20	20	30	34	36	38	40	44	58	61

From the data collected, work with the class to identify the five-point summary, which includes the *minimum*, *first quartile* (Q1), *median*, *third quartile* (Q3), and *maximum*. For the set of data shown above:

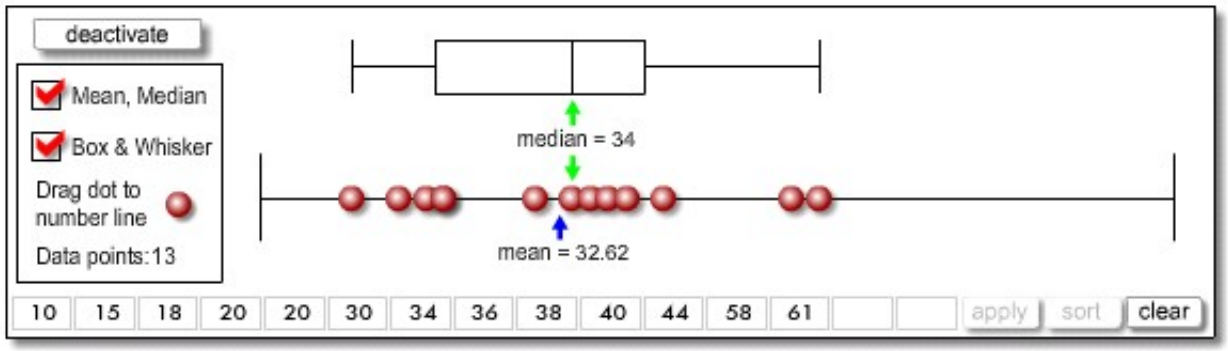
- Minimum: 10
- First Quartile: 19
- Median: 34
- Third Quartile: 42
- Maximum: 61

Construct a large box-and-whisker plot of the data set on your whiteboard. Students should use the Mean and Median Tool to create the box-and-whisker plot. If your class has fewer than 15 students, you can do this as a whole class activity. If your class has more than 15 students, divide them into two or more groups, and allow each group to enter their data into this tool to create a box-and-whisker plot. (Later in the lesson, students will be given an opportunity to create a

second boat and compare their data from the first and second attempts. Consequently, the groups should remain intact throughout the lesson.)

Mean and Median Tool

If you have divided your class into two or more groups so that they could use the Mean and Median Tool, select one group to use as an example, and draw a large box-and-whisker plot of their data on a whiteboard, chalkboard, or overhead projector. Place the actual boats from the example group in order from best to worst under or near the box-and-whisker plot, so that the students can associate each boat with its placement in the graphical display. Have them note which boats are near the five-point data values. For the data set above, the Mean and Median tool would generate the following box-and-whisker plot, which could be projected on a screen or interactive whiteboard:



After the students look at the boats, their positions on the plot, and their capacities, ask, "Now that you have seen this information, do you think you can build a boat that will hold more bears?" Their response, of course, will be an overwhelming, "Yes!"

Give each student another piece of foil. Students will closely examine the boats with the greatest capacities before building their second boat.

Again one at a time, have students place their boat on a lake and carefully load it. Repeat the steps above for collecting and sorting the data, and drawing a second box-and-whisker plot above or below the first one. (This can be accomplished easily using the Mean and Median Tool, which allows for up to three box-and-whisker plots to be constructed and compared.)

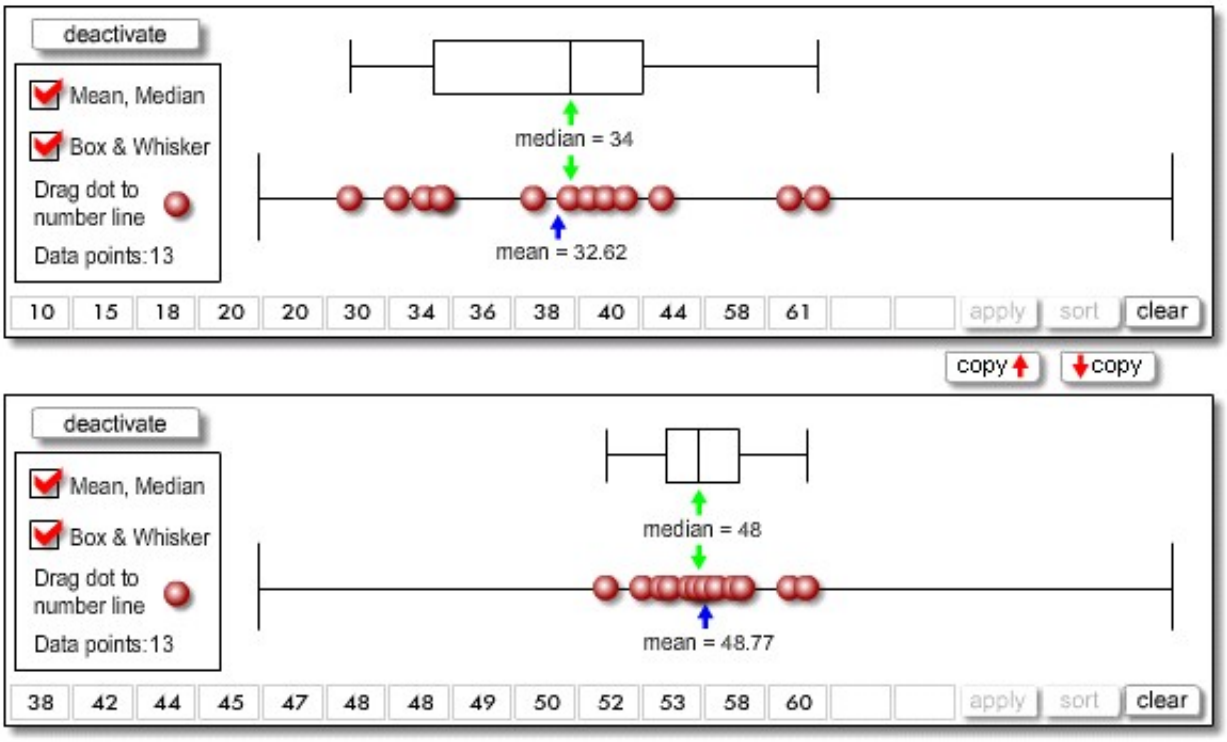
The results of the second distribution will be remarkable. A typical second try is shown below:

Student	Ada	Ben	Cal	Dee	Eve	Fae	Gia	Hal	Isa	Jen	Kay	Lue	Mai
Capacity	38	42	44	45	47	48	48	49	50	52	53	58	60

For this second set of data, the five-point summary is:

- Minimum: 38
- First Quartile: 44.5
- Median: 48
- Third Quartile: 52.5
- Maximum: 60

The Mean and Median tool will generate the following box-and-whisker plots for comparison:



Ask students to compare the box-and-whisker plots. What can these representations tell them about the data, and how can they be used to analyze the results of the first and second attempts?

The results shown above are typical, and students' second attempts are generally far superior to their first attempts. Consequently, the results from your class will have similar characteristics, and students might make the following observations:

First Attempt		Second Attempt
median	≤	minimum
third quartile	≤	first quartile
maximum	≈	maximum

- The moral for students is that if the first attempt had poor results, then the

use of new information and careful effort can lead to significant improvement; but if the first attempt result was exceptional, it is hard to meet that goal every time.
- The large capacity boats will generally look similar — typically large square bottoms with carefully folded sides of medium height. They will resemble the barges that can be found on large rivers, such as the Ohio or Mississippi.

To conclude the lesson, ask students what they have learned. You may be surprised at all that students will share. In addition to mathematical observations, students may offer the following:

- The organization and analysis of the data helped us to "learn by our experiences."
- Students probably talked about the data and the attributes of the boats with each other before building their second boat. This reinforces that communication is important — both talking and listening.
- Each representation of the data (table, box-and-whisker, and actual boats) gives us different perspectives and insights.
- There is probably a "perfect boat design," but the physical environment, human error, and potential motion of the water may make it difficult to build and fill the boat perfectly. This is a reminder that theory and practice must mesh in the real world.

Questions for Students

What are the five elements of a five-number summary?

> [The minimum (0%), first quartile (25%), median (50%), third quartile (75%), and maximum (100%). The five-number summary divides the data set into four pieces of roughly equal size.]

What observations can be made when the box-and-whisker plots from the first and second attempts are viewed side-by-side?

> [Answers will vary, but students may notice that the minimum of the second attempts exceeded the median of the first attempts or that the maximum of both attempts was similar.]

What is the most effective boat design?

> [A boat with a square bottom and medium height sides seems to work best. The precision of the folds also appears to have an effect.]

Assessment Options

1. Allow students to research a topic of interest to them and find a set of data on the Internet. For instance, they could research sports statistics and find the heights of the members of an NBA team, or they could research weather and find the monthly high temperature for the last year. Then, have students use the data to generate a five-number summary and create a box-and-whisker plot.
2. Ask students to complete an "exit card" before they leave class. The prompt for the card could be, "What is one thing you learned from today's activity?"

Extensions

1. Pair students in your class with students in a calculus class. Working together, can they create a better boat design? Or perhaps a middle or high student with some knowledge of science and physics could talk to the entire class about factors to consider when designing a boat.
2. Ask students to identify the maximum volume that could be held by the folded piece of aluminum foil. This question is equivalent to the famous calculus question, "What is the maximum volume of an open-top box created by cutting small squares from the corner of a larger square and then folding up the sides?" Although it is difficult to fold the sides of the aluminum foil precisely, it is certainly possible to make a close approximation to this optimal design.

Teacher Reflection

- Were students engaged throughout the lesson? If not, what could be done to minimize distractions?
- How were you able to get students to focus on the math, instead of just viewing this as a fun activity?
- How did you handle the transitions during the lesson, to get students to move from the lakes to the computers and back again? What could be done to improve this the next time?

NCTM Standards and Expectations

Data Analysis & Probability 3-5

1. Collect data using observations, surveys, and experiments.
2. Describe the shape and important features of a set of data and compare related data sets, with an emphasis on how the data are distributed.

Data Analysis & Probability 6-8

1. Select, create, and use appropriate graphical representations of data,

including histograms, box plots, and scatterplots.
2. Use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken.

Geometry 3-5

1. Identify, compare, and analyze attributes of two- and three-dimensional shapes and develop vocabulary to describe the attributes.

This lesson prepared by Jim Rubillo.

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