Activities Utilizing Student-Generated Data: Experimenting with Experiments

Diane Evans and Mary Rose Silva
Rose-Hulman Institute of Technology, 5500 Wabash, Terre Haute, IN 47803

Abstract
This article describes two fun in-class activities that students can do to generate their own data for statistical analysis.

Keywords: Teaching; Practical activity; Probability; Statistics

1. Introduction

In my Engineering Statistics I course, students are excited to do in-class labs if they involve data that students generate themselves. Over the past ten years, I have been able to determine some of the activities that work the best for a 50-minute class period. The short amount of time that students spend obtaining their own data at the beginning of class period is well worth their increased energy and motivation in determining solutions based on this real data. In this article, I will discuss two activities that can be completed in one or two class periods and provide data for explaining and computing basic probability values and performing statistical inference with a paired data set. The time and money required to prepare for these activities is minimal, and I will provide a list of problems to accompany them. The first activity is based on the game "Pass the Pigs," and the other activity involves comparing water displacements of students' dominant and non-dominant hands.

Why do these activities? Data analysis is a very important step in the scientific inquiry process; however, too often it is overlooked. With limited classroom time and crowded syllabi, data analysis is often taught in isolation as students are assigned research questions with accompanying clean datasets. By getting students involved in steps such as question and data generation, they become more interested and vested in the analysis step. Additionally, students often report that they feel more prepared to tackle research questions in the future as they have experience with study design and development of a data acquisition plan (two topics we rarely address in statistics courses). Presented are ideas for and issues surrounding activities that utilize student-generated data. By doing such activities, a teacher provides his or her students a research experience, not just a research assignment.

2. Activity 1: "Pass the Pigs"

2.1 Materials Needed

- 2 plastic or rubber pigs that have one dot on one of its sides
- Scorecard

The official "Pass the Pigs" game by Milton Bradley (now owned by Hasbro) is sold at toy stores for about $12. The game contains two plastic pigs that have a dot on one side and a score card. If the official game is too expensive for you, you can get similar types

of pigs or other animals at crafts stores for about 8 pigs for $6. See Figure 1. There is also an on-line version of the game that can be found at http://www.censusonline.net/games/pigs/passthepigs.html.

Figure 1: Two plastic pigs for "Pass the Pigs" game

2.2 How to Play

- Take two pigs and roll them like you would a pair of dice.
- The pigs will land in various positions. Each position or combination of positions results in different scores. Your score can increase or decrease depending on how the pigs land. (See Appendix for scores for various pig positions.)
- You can roll the pigs as many times as you like. Your turn ends when you decide to stop rolling and pass the pigs to the next player, or when you get a "Pig Out" (Figure 2) whereby your score goes back to zero for that turn.
- The first person to get 100 points wins the game.

Figure 2: Pig Out: Pigs land on different sides with one on its dot side and the other on its non-dot side.

2.3 Playing the Game as a Classroom Activity

1. Split the class into teams of 4 players with a pair of pigs.
2. Teams review the rules of the game and scoring for the pig landing positions.
3. One team member is the score keeper.
4. Another team member records the pig landing positions for each roll in a chart like the one in figure 3. For example, a double trotter would a count as 2 separate trotters. Two hash marks then would be recorded in the column "Trotter."
5. Instructor tallies totals for entire class for pig landing positions.

Dot Side	Non-Dot Side	Trotter	Razorback	Snouter
𝍸	𝍸	𝍸	𝍸	𝍸

Figure 3: Sample chart showing the frequency of pig landing positions

In the Fall of 2013, I had my class play "Pass the Pigs." Figure 4 shows the students results and the probabilities they calculated based on these results

Dot (D)	Non-dot (ND)	Trotter (T)	Razorback (R)	Snouter (S)	Total Single Rolls = |D| + |ND| + |T| + |R| + |S|
784	841	224	897	39	2785
$P(D) = \frac{784}{2785} \cong 0.282$			$P(ND) = \frac{841}{2785} \cong 0.302$		
$P(T) = \frac{224}{2785} \cong 0.080$			$P(S) = \frac{39}{2785} \cong 0.014$		

Figure 4: Results from Fall of 2013 class

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2.4 What Can You Do with the Data Obtained?

The data obtained from playing "Pass the Pigs" can be used to teach concepts such as:

- Sample space construction,
- Relative frequency definition of probability,
- Basic probability computations: union, intersection, conditional,
- Probability terminology: complementary, independence, mutually exclusive,
- Distributions, such a binomial, using pig landing probabilities,
- Expected value and variance of distributions,
- Simulation via a computer algebra system, and
- Use of real data to compute actual probabilities.

Some specific problems relating to these concepts are:

Conceptual Questions:

1. When computing probabilities, such as *P*(Sider), is Pig 1 = D and Pig 2 = ND "different than" Pig 1 = ND and Pig 2 = D?
2. How many outcomes are in the sample space for rolling 2 pigs?
3. When rolling 2 pigs, are events D and ND independent?
4. When rolling a single pig, are events D and ND mutually exclusive? Complementary? Independent?
5. Since D and ND are just the two sides of a pig, why isn't |D| = |ND|?
6. Are 2785 rolls enough to determine the true probabilities of these events? If not, what number of rolls is enough?

Computational Problems:

1. When rolling one pig, determine $P(D \cup ND)$.
2. When a pair of pigs is rolled, determine:

(a) *P*(Double Trotter)
(b) *P*(Pig Out)
(c) *P*(Pig 1 lands D | Pig 2 lands ND)

3. What's the probability of obtaining at least one Snouter in 100 rolls of a pig?

A Simulation Exercise

1. What is the expected number of rolls until a Snouter (S) is obtained?
Hint 1: Use a computer algebra system, such as Maple, to automate the experiment of rolling a pig and determine the result through simulation.
Hint 2: Determine the expected number of trials until success for a simpler event with probability of success *p*. Experiment with flipping a coin and determining the average number of flips until the first tail.

2.5 Conclusion

Games like "Pass the Pigs" are so well received by students because:

- Students like games. Time for a team to play, crown a winner, and record results is 5 - 10 minutes.
- Students remember fun exercises and concepts that go with them.
- Students can conceptualize probability concepts through an activity that they understand; e.g., Pig 1's outcome does not affect the probability of Pig 2's outcome: independence!
- Students enjoy performing computations on data that they collected.
- Students will play the game beyond class time by downloading it, purchasing it, or writing the code for it themselves.

Activity 2: Comparison of Hand Water Displacements

3.1 Background

The comparison of hand water displacements is a more involved activity than "Pass the Pigs," but data can still be obtained in one 50-minute class period. The idea for the activity came about after I was involved in a bad bicycling accident. I broke my right elbow and broke a bone in my left hand. I had to wear two casts for approximately six weeks. See Figure 5.

Figure 5: Diane after her bicycle accident

After the casts were removed, I started physical therapy. On the first day, my therapist needed to determine how much swelling I had in my injured left hand. She filled a tank, called a volumeter (see Figure 6), with water and had me place my left hand in it. Water was displaced from the top of the tank through a small opening with an attached downward spout into a graduated cylinder. The volume of the displaced water in the cylinder was measured and recorded. Then the same procedure was done with my non-injured right hand. Using the volume of displaced water for each hand, the therapist was

able to determine the approximate percentage of swelling in my injured left hand compared to my non-injured right hand.

The techniques and equipment my physical therapist used to check for swelling in my hand inspired me to create an activity pairing data in a two-sample experiment. For this experiment, I measured the amount of water displaced by a person's dominant and non-dominant hands. This activity was geared toward high school and college students in statistics courses. Students in an entry-level statistics course often have a hard time determining when to pair data in a two-sample experiment. Since the activity requires students to separately submerge their dominant and non-dominant hands in the water tank for dispersion readings, I felt confident that the activity would drive home why the data must be paired for further testing.

3.2 Materials Needed

- Hand Volumeter
- Graduated Cylinder
- Water
- Paper Towels

3.2.1 Special note on our volumeter

The volumeter used by my physical therapist cost over 250 US dollars. Since my budget could not support an expensive volumeter, I asked Elizabeth (Liz) Evans, an undergraduate math major at our college, to assist me in constructing a volumeter.

Liz and I first considered ways to construct a volumeter with an ordinary spouted pitcher. Although this worked for collecting the dispersed water, we wanted a tank that could give us more precise data. So, we decided to build our own volumeter. After much research and trial and error, we finally designed a volumeter that we believed was workable. See Figure 7.

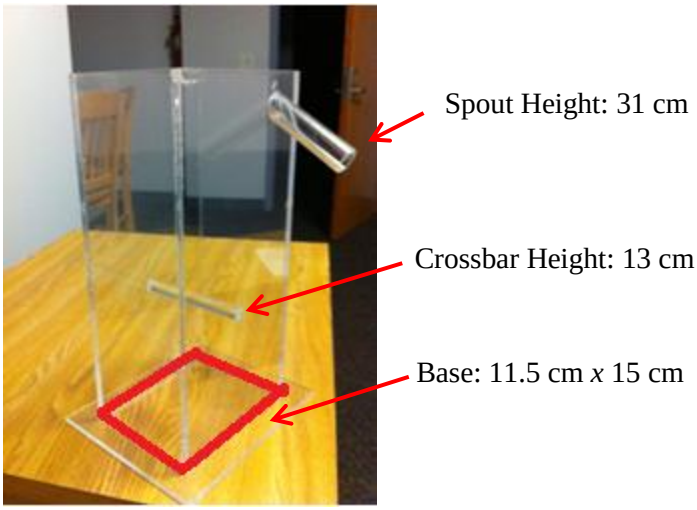

Figure 6: Our homemade volumeter with height measurements starting from the base

Our volumeter had the following dimensions, with height measurements starting from the base:

- Base of volumeter: 11.5 cm *x* 15 cm. For stability, the bottom panel was cut several inches larger in each direction than the volumeter base.
- Height of side panel: 35 cm
- Height of crossbar: 13 cm
- Height of spout: 31 cm

3.2.2 A simplified volumeter

Many professors reading this article may not have access to acrylic sheets and tubings or a machine shop. We found we could construct a basic volumeter using an ordinary pitcher with a spout and a measuring cup. Use a pitcher that is large enough so a person can put his/her entire hand in it without touching the bottom. Fill the pitcher with water up to the spout and place the measuring cup under the spout to collect the displaced water when participants immerse their hands into the pitcher. Have some rule or mark for a visual stopping point for submerged hands, and you have your own water displacement tank. With the simplified volumeter, the activity can be performed by elementary or middle school students, and teachers can modify the activity questions so they are appropriate for a particular education level.

3.3 Activity Description and Questions

The procedures for this activity are quite specific and should be followed carefully in order to get accurate data. In the analysis of the data, students will be able to see whether the procedures that they followed introduced errors in their measurements, and allow them to think of ways to improve the accuracy of their data. Figure 7 is a water displacement activity handout for introductory statistics students that includes the steps to do the experiment and sample problems.

Water Displacement Activity

Activity Introduction:

At the front of the classroom, we have a tank called a **volumeter** which is used for measuring water displacement. If you have had a hand or foot injury, you may be familiar with it. Physical therapists use volumeters to measure the amount of swelling in an injured limb by comparing the amount of water displaced by the injured limb with the amount of water displaced by the uninjured limb.

For today's activity, we will use the volumeter to compare the amounts of water displaced by your dominant hand versus your non-dominant hand. If they displace the same amounts of water, this shows that the volumeter is a useful tool for comparing one hand against the other when injuries involving swelling have occurred. In other words, for a person who has sustained a hand injury, measuring the amount of water displaced by his/her injured and uninjured hands is a good baseline comparison for determining the amount of swelling in the injured hand.

Directions:

1. Before beginning the experiment, provide an operational definition for the term "dominant hand." Consider that some people may use different hands for different activities; e.g., they write with their right hands, while throw with their left hands. Also, what about people who are ambidextrous? Make sure your operational definition clearly identifies which hand should be used as the dominant one in this activity. There are many possible correct definitions; the goal is to write a clear and explicit one.

Figure 7: Water Displacement Activity Handout

2. Volunteers are needed to record water displacement amounts.

3. Make sure the water level of the volumeter is set to the height of the spout.

4. For the first measurement, a student will SLOWLY immerse her dominant hand into the volumeter until her middle and ring fingers straddle the crossbar. The overflow of water will be captured and measured (in mL) in a graduated cylinder. Record the measurement.

5. Fill the volumeter again with water up to the height of the spout.

6. The same student will SLOWLY immerse her non-dominant hand into the volumeter until her middle and ring fingers straddle the crossbar. The overflow of water will be captured and measured in a graduated cylinder. Record the measurement.

7. Repeat Steps 3-6 two more times with the same student. Make sure that the student's hands and the graduated cylinder have been dried before the student immerses her hands into it.

8. After 3 measurements have been taken for the student's dominant and non-dominant hands, the process can begin again with a different student.

9. Put all the recorded measurements on the front board.

Activity Questions

1. Construct a table putting in the actual measurements that have been recorded on the front board. As an example, I have placed some sample data in the columns below for demonstration purposes only.

	Dominant Hand			Non-Dominant Hand		
Person	Vol.A (ml)	Vol. B (ml)	Vol. C (ml)	Vol. A (ml)	Vol. B (ml)	Vol. C (ml)
1	395	401	403	410	400	420
2	470	455	490	425	410	428

2. For a given person, compare the three measurements for the dominant hand. Do the three measurements differ by a small amount or a large amount? What does this indicate about the measurements? Do the same for the non-dominant hand.

3. For each person, calculate the average amount of water displaced by the dominant hand. Do the same for the non-dominant hand. Why would you want to calculate the average? What other statistical calculations might you use?

4. How do the average amounts of water displaced by the dominant hand compare to the average amounts displaced by the non-dominant hand for each person?

5. Assume that the students in the class represent a random sample of the college's student population. For this population, is the true average water displacement for the dominant hand different than the true average displacement for the non-dominant hand? Set up the appropriate hypothesis test below to answer this question.

H_0: H_a:

6. What type of test are you going to perform? Make sure you understand why and have checked all necessary assumptions!

Two Sample *z* Two Sample *t* Paired *t* ANOVA

7. What is the *p*-value for this hypothesis test using the class's sample data?

8. What is your decision regarding the null hypothesis with significance level of $\alpha = 0.05$? Reject or do not reject H_0? Briefly state why.

9. What does the study suggest to you about the use of water displacement tests to measure swelling in a person's injured hand?

Figure 7: Water Displacement Activity Handout (cont.)

In order to have this activity apply to a larger educational audience, I provided sample topics and questions (Figure 8) geared towards understanding basic concepts dealing with conducting the experiment, collecting data, analyzing data, and drawing conclusions based on the results of the experiment.

TOPIC	ACTIVITY QUESTIONS
Defining the term "dominant hand"	Which hand does the student use when he/she is writing? Throwing a ball? Hitting a ball with a bat? Brushing his/her teeth? Buttoning his/her shirts?
Reliability of measurements	<u>What factors would affect the reliability of the measurements?</u> 1. Were the instructions for the experiment exactly followed? 2. Were the hands being stopped at the same level? 3. Was the volumeter filled up to the spout for each trial? 4. Were measurements recorded correctly? 5. Was the graduated cylinder or measuring device dry before each trial? Were the students' hands dry before each trial? 6. Was there any water that was not caught by the graduated cylinder? 7. What other factors should be considered when determining whether the measurements are reliable? 8. What changes should be made to get more reliable data?
Number of samples and measurements	1. How many students should partake in the experiment for statistical accuracy? 2. How many times should each student's hand be measured for statistical accuracy?
Other studies that can be done using this activity	Example Study 1. A water displacement experiment can focus on male versus female hands. What conclusions can be made about male hands? About female hands? Example Study 2. A water displacement experiment can focus on athletes versus non-athletes. What conclusions can be made about hands of athletes? About hands of non-athletes? What information should be added to the data chart in order to obtain the necessary information for other studies? Gender? Athlete or Non-Athlete? Age?
Volumeter	1. How do you know if the volumeter is large enough for what you are trying to measure? 2. What changes to the volumeter should be made when measuring displacement amounts of a person's feet? Legs? Arms? 3. In addition to swelling of a limb, can a volumeter be used to detect other physical ailments or injuries? 4. Can other liquids be used other than water?
Results/Conclusions	1. How can we use graphs to examine the data? 2. What do the different graphs show? 3. What conclusions can we make based on the graphs?

Figure 8: Additional sample topics and questions related to the volumeter experiment

When my students did this activity in class, we had 14 participants. Although there were more students in the class, we did not have enough time in a 50-minute class period to collect data from everyone because we repeated the dominant hand and non-dominant hand displacement amounts three times per hand per student. We used the average of the three measurements for each hand in order to compensate for repeatability issues in the measurement system. If there were large differences between subjects' measurements, then using subject averages instead of raw measurements would not reduce the standard error very much. On the other hand, if the volumetric measurement variability was large compared to the differences between subjects, then averaging would be beneficial in terms of decreasing the standard error and increasing power.

The average time to collect these six measurements per student was approximately three minutes with a standard deviation of 30 seconds. Displayed in Figure 9 are the actual measurements of the first three participants from our in-class experiment.

	Dominant Hand			**Non-Dominant Hand**		
Person	Vol. A	Vol. B	Vol. C	Vol. A	Vol. B	Vol. C
1	375.0	400.0	405.0	410.0	400.0	400.0
2	465.0	440.0	445.0	470.0	462.5	450.0
3	450.0	467.5	465.0	440.0	435.0	440.0

Figure 9: Actual dominant and non-dominant hand measurements for the first three participants from the in-class experiment

With our 14 participants, we found that there is no statistical difference in the water displaced by dominant versus non-dominant hands in the volumeter. Our class data resulted in an average "dominant – non-dominant" hand difference of 2.80 milliliters. The resulting *t*-test statistic was $t_0 = 0.56$ with a *p*-value of 0.583 for the two-sided alternative hypothesis. Thus, using one hand as a baseline measurement for the other hand, especially when one of them has been injured, is credible.

3.4 Conclusions

The most important aspect of letting students do hands-on activities is that it allows students to be active participants whereby they actually get to experience what it is like to conduct an experiment, obtain data, analyze the data, and think of ways to improve their processes. With respect to doing experiments like the hand water displacement measurements, students learn:

1. Collecting accurate data in an experiment is very important, and that various factors should be considered because they may affect the data;

2. Although an experiment is conducted in the same manner three times, measurement errors do occur. For example, a milliliter is a small measurement unit for noting differences in water displacement amounts, and even a drop or two still clinging to the exit spout can affect the reading on the graduated cylinder. Also, although the submerged hand is stopped by the crossbar, there can small differences in hand immersions into the volumeter (such as tilt, which fingers placed between the crossbar, etc.) on successive trials by the same person affecting displacement amounts; and

3. Defining key terms in the experiment may not be so easy to do. Key terms in an experiment must be clear and precise. Thus, while we may instinctively know which

hand is our “dominant hand” and which one is our “non-dominant hand,” defining these terms for an experiment may be difficult because people may use one hand for one of activity and the other for another activity.

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The slide presentation is available at:
https://drive.google.com/file/d/0B5lWUUC5Zn3gUlFwa0UtbEI4R3c/edit?usp=sharing

APPENDIX

Scoring for “Pass the Pigs”

Name of Pig Position	Description	Score - Points
Sider 	Both pigs land on the same side	1
Razorback 	One pig lands on its back Both pigs land on their backs	5 20
Trotter 	One pig is upright (on its feet) Both pigs are upright	5 20
Snouter 	One pig lands on its snout Both pigs land on their snouts	10 40
Pig Out 	Both pigs land on different sides	Player's score goes back to zero for that **turn**
Oinker 	Pigs are touching	Player's score goes back to zero for the **game**