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What is the Length of a Toilet Paper Tube? A Hands-On, Team-Based Lesson in the Ethics of Data Collection

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Dr. John R Luchini

Dr. John R. Luchini (1949-2013) earned his Bachelor, Master, and PhD degrees in engineering from the University of Michigan. In 2011, John retired as Senior Research Scientist and Engineer after a 34 year career with the Cooper Tire and Rubber Company in Findlay, Ohio. He was a Fellow of the American Society of Mechanical Engineers; a registered Professional Engineer in the State of Ohio; and served for 44 years as a national volunteer for Tau Beta Pi, the engineering honor society. A life member of the Society of Automotive Engineers, John served for 35 years as chair and member of SAE committees involved in developing government standards and regulations for the tire industry. He was a member of the Industry Advisory Board for Physics at Kettering University for 17 years and served for 34 years as a charter member and journal editor for the Tire Society. John's numerous teaching experiences included developing and presenting curriculum on interpersonal communications and engineering problem solving in a variety of forums, including as a Dale Carnegie Instructor and a Facilitator for the Engineering Futures program of Tau Beta Pi.

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Abstract

We describe a hands-on, team-based classroom activity designed to help engineering students understand the ethics of data collection, analysis and reporting processes. This lesson is presented to students as a "mini research competition" involving the collection of data to answer the question "what is the length of a toilet paper tube?" The lesson is purposely structured to both provide opportunities for ethical behavior and to offer temptations and rewards for cheating. The initial activity is followed by a substantial discussion and debriefing, and the lesson concludes with several related case studies for discussion within student teams. Discussions about this lesson focus on several questions: What are the ethical issues involved in collecting, analyzing and reporting data? How do documentation and reporting processes impact the ethical conduct of research? How does working in a team impact data collection, and what responsibilities do individuals have in ensuring that the team's activities and outputs meet ethics standards? We also describe the evolution of this ethics lesson from an earlier classroom activity involving precision and accuracy in data measurement, which has been used in high school, college and continuing education settings for more than two decades. This paper describes the development of the curriculum; lessons learned from the classroom; and an analysis of student artifacts from the most recent offering as part of an engineering undergraduate research program at Michigan State University. The lesson materials are provided in appendices, in order to allow other educators to adapt these materials for their own classrooms.

Background: Ethical Practices in Research

Kenneth D. Pimple summarized the responsible conduct of research (RCR) as the search for "truth, fairness and wisdom."[1] This search for truth means considering whether the data are gathered and presented in a manner that is consistent with the physical world. Fairness considers the accompanying social relationships: is appropriate credit given where it is due? Are research subjects treated humanely? Are funding relationships acknowledged, and is funded research free from outside influences? Pimple's final criterion, wisdom, "concerns the relationship between the research agenda and the broader social and physical world, present and future" and asks whether the proposed research is the best possible use of finite resources.[1]

Within the broader context of RCR are more specific questions about the ethics of collecting, analyzing and reporting data. While "the search for truth and its unbiased reporting are ultimate goals of conducting scientific research,"[2] there are both implicit and explicit pressures that may lead to bias or fraud in data management. There may be valid reasons to exclude outlying data points, but researchers must carefully consider whether such exclusion criteria might change the interpretation of the remaining data. It is also important to include all pertinent data in its most authentic format; for instance, it can be tempting to report percentages rather than numerical values, or to downplay or exclude participant numbers for small experiments. However, these data should be clearly included in order to provide an appropriate context for interpreting the impact of the results.[2]

Research programs for undergraduates often include RCR training,[3–6] and focused RCR instruction has been shown to increase students' understanding of research ethics during a REU (Research Experience for Undergraduates) summer program.[7–9] The ethics of data collection, analysis and reporting are an important topic for many REU programs, and can lead to broader conversations about RCR and the ethical challenges researchers may face:

> *Advising [REU] students on how to write up their research seemed a good time to talk about what counts as data, how outliers should be handled, what must be included in a report, the reasons certain data may be omitted (and how that should be done), and even the importance (and effect) of putting some point first (or burying data in a table at the back of the report). Such a discussion might naturally open a wider discussion of the ethical aspects of the relationship a researcher has with funders and with those who may use the research (for example, what innovations may be published or what warnings should go into a report).*[10]

Learning to collect accurate, precise data is also an important component of many engineering curricula. Past researchers have explored many aspects of data collection, analysis and reporting, such as error analysis,[11] scientific measurement,[12] and laboratory procedures.[13]

From Accuracy and Precision to Ethics: Evolution of the Curriculum

The ethics exercise described here evolved from an earlier lesson on the difference between accuracy and precision in scientific measurements. While accuracy and precision are often used interchangeably, they have distinct meanings in the context of scientific measurements. An accurate measurement reflects the true value (possibly within an error range or degree of confidence), while a precise measurement is consistent and repeatable.[14] It is possible for a measurement to be highly accurate but not precise (repeatable), or to be very precise but not accurate (reflecting the true value). Figure 1 depicts the difference between accuracy and precision in scientific measurement.

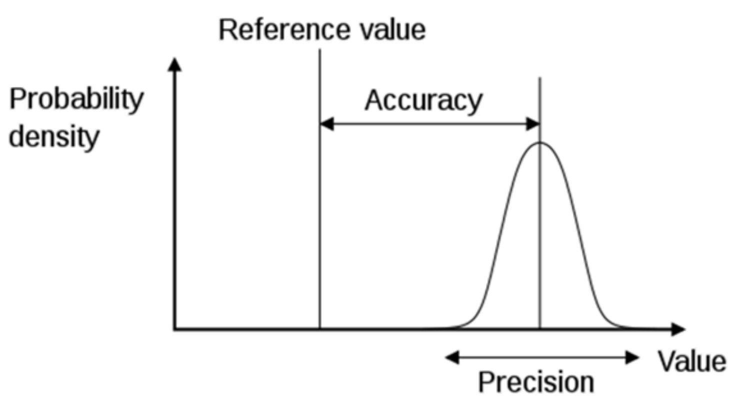

Figure 1: Accuracy is the proximity of measurement results to the [reference] true value; precision, the repeatability, or reproducibility of the measurement. Figure and caption from Pekaje/Wikipedia.[15]

The initial lesson on accuracy versus precision was developed by Dr. John R. Luchini as part of a guest lecture for a high school science class. Students were asked to collect empty toilet paper tubes in advance, and worked in small groups to measure the tubes in various ways. Some groups focused on accuracy, measuring with calipers or rulers, while other groups focused on precision: obtaining consistent, repeatable results by dropping tubes onto graph paper (of various resolutions) and counting how many graph lines were covered. Individual results from each group were then combined and analyzed in various ways to explore the precision and accuracy of different measurement methods—and the impact of varying the size of the data set. The measurement and analysis process was complicated by the fact that individual manufacturers are free to determine the length of their own toilet paper rolls. While many tubes are about 4 inches long,[16] there is enough variation in length to prompt interesting conversations among students about accuracy, precision, error rates and confidence intervals.

This lesson was repeated and refined over more than two decades, both in high school classrooms and as part of professional development seminars and continuing education classes for college students and practicing engineers. Over time, the lesson expanded to include discussions about ethical issues related to data collection, analysis and reporting. Many of these expansions were inspired by questions raised by students; for instance, what should they do with the paper towel tube that someone brought to class? Some students argued for simply excluding the data point, since it did not match the desired input (toilet paper tubes). Others suggested modifying the data, by cutting the paper towel tube into one or more lengths that were similar to toilet paper tubes. These questions led to conversations about data falsification and fabrication, about when it is appropriate to exclude outlying data—and how to document and report such exclusions.

As an alternate approach, Dr. Luchini suggested that students include the measurement from the (unmodified) paper towel tube in their data set and see what happened. Not surprisingly, the longer tube skewed the average length calculated within the small group that measured it; however, once their data were combined with results from other groups the overall average approached 4 inches. This led to a memorable conversation about the impact of data set sizes, and additional ethical considerations about collecting the “right” number of measurements: enough to allow confidence in the results, while not so many that resources are wasted unnecessarily.

Methodology

In Summer 2015, the toilet paper tube exercise was adapted for use in the summer research program sponsored by Michigan State University (MSU). This 10-week summer program served approximately 120 students and included a 90-minute professional development seminar each week. As part of these seminars, students were randomly assigned to a four-person team that worked together on professional development activities throughout the summer program. Due to the large size of the program, these seminars were held in an auditorium-style room with fixed seating in raised rows. Although this layout is not ideal for small group activities, there was enough room for student groups to spread out a bit and over the course of the summer program student teams claimed “their” sections of the room.

The seminar on research ethics happened in the fourth week of the 10-week summer program (Table 1 summarizes the calendar of professional development activities). Students were encouraged to bring in empty toilet paper tubes but otherwise were not told anything about the topic or content of the lesson in advance. The competition was introduced to students in a single PowerPoint slide (shown in Figure 2) that outlines the key parameters, including a 10 minute time limit, the requirement to complete a written report, and prizes that would be awarded to the team that finished first, the team with the most data points, and the team with the most accurate result. The 10-minute limit was selected for this particular setting because it was sufficient time for students to complete the exercise, yet provided a deadline that pressured students to work quickly—which might tempt them to “cut corners” in order to finish within the time limit.

The 10-minute timer began when the slide shown in Figure 3 was displayed, which contained the research question for the competition: “What is the length of a toilet paper tube?” Each team had to send a representative to the front of the classroom to pick up a research report template (as shown in Appendix A). Next to the research report template was a stack of 12” paper rulers with both metric and English markings; the availability of these rulers was not announced in class, since the instructor did not want to dictate how students completed their measurements. However, the rulers were clearly visible and many students picked them up. As the student teams completed their research reports, they turned them in to the instructor at the front of the classroom. When the 10-minute timer rang, all of the teams’ reports were collected and the instructor facilitated a debriefing discussion about the ethics of data collection, including the prompts shown in Figure 4. The debriefing lasted about 30 minutes, and afterwards students worked in their teams to review two case studies on the ethics of data collection drawn from work by Branchaw, Pfund and Rediske[17] and the National Academies;[18] the case study handouts used in this exercise are included as Appendix B. Approximately 30 minutes was allocated to this review of the case studies in small groups, with a final 10-minute large group discussion on the case study scenarios. (The remaining 10 minutes of the 90-minute seminar was used for “housekeeping” tasks like announcements, time to transition between activities, etc.).

Table 1: Summary of Professional Development Activities

Week	Activities	Assignments Due
1	• Program Orientation • **Seminar:** Tools and Techniques for Literature Reviews	
2	• **Seminar:** Developing Abstract & Research Paper	• Mentor-Mentee Contract • Research Report #1
3	• **Seminar:** Developing Effective Research Posters	• Research Report #2
4	• Networking Lunch with Graduate Students • **Seminar:** Research Ethics	• Poster Abstract Draft • Research Report #3
5	• **Seminar:** Career Options for MS and PhD Recipients	• Annotated Bibliography • Research Report #4
6	• Networking Lunch with Faculty Member • **Seminar:** Graduate Programs & Application Processes • Research Poster Symposium Registration	• Research Paper Outline • Research Report #5 • Poster Title & Abstract
7	• Seminar: Academic Resumes	• Grad App Statement • Research Report #6
8	• Seminar: Student Research Presentations	• Academic Resume • Research Report #7
9	• Seminar: Leveraging Undergrad Research Experiences	• Final Research Poster • Research Report #8
10	• Research Poster Symposium • Closing Picnic	• Final Research Paper • Research Report #9, #10

Figure 2: Slide projected to introduce students to research competition.

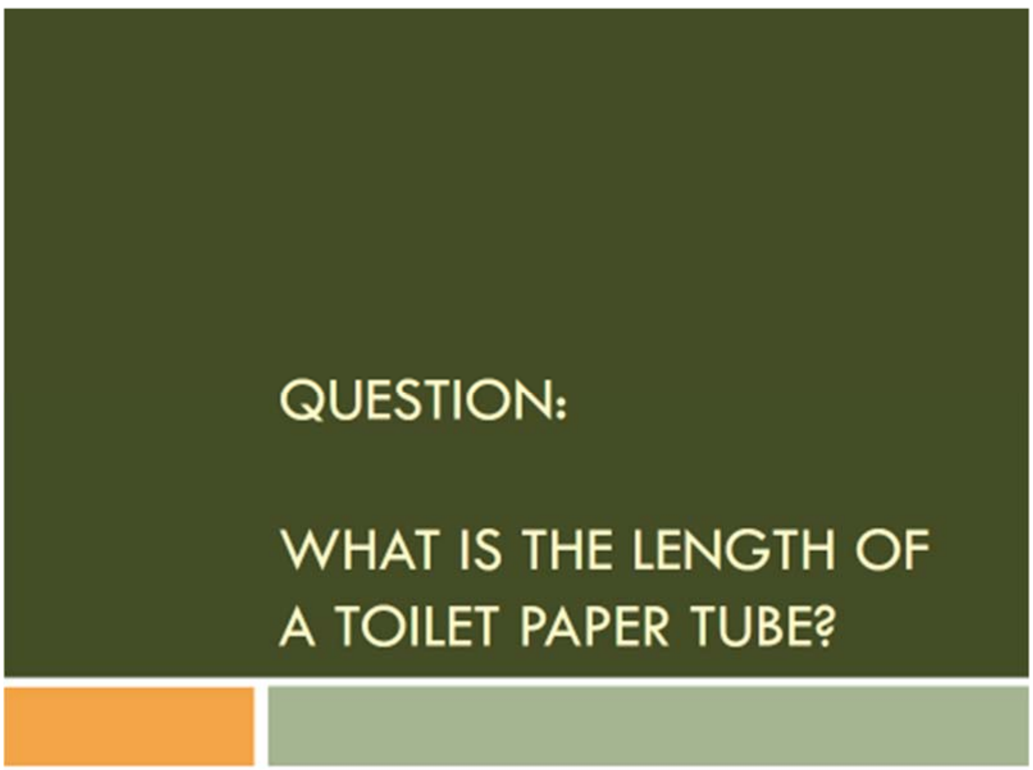

Figure 3: Research question slide displayed to start the competition.

Figure 4: Discussion prompts for post-activity debriefing.

Results

92 total students participated in this ethics exercise during the 2015 EnSURE(Engineering Summer Undergraduate Research Experience) program at MSU. The students were divided into 24 teams, which were randomly formed on the first day of the summer research program and worked together throughout the professional development seminar series. Each of the 24 teams turned in a written report (sample in Appendix A) of the activities they completed during the ethics exercise, as summarized in Table 2. Students were asked to describe their methodology, and all but one team included a description of their measurement technique. While most of the teams (14 of 24) chose to use the paper rulers provided in class, 3 teams relied solely on internet search results and 6 teams developed more creative measurement techniques. Examples of these "other" measurement methods include:

- A measurement technique using the rings on a spiral-bound notebook
- A measurement technique using graph paper
- Comparing the toilet paper tube to a sheet of paper of known dimensions
- A model developed using participants' thumbs as substitutes for a physical tube

Students were also asked to indicate the type of data they analyzed as part of this exercise. All but 3 teams indicated how many tubes they measured. 4 teams reported that they had zero physical tubes to measure and 2 teams had 15 or more tubes to work with; the remaining teams had 1-4 tubes to measure. Students also listed their data points, and many teams measured the same tube multiple times. For example, one team indicated that their method was to "measure [each tube] twice by two people" so that they generated 8 data points from 4 toilet paper tubes. The team with the most data points had 18 tubes and measured each one time; several teams reported that they had 0 tubes and thus had 0 measurements, while other teams recorded measurements taken from internet search results.

Not surprisingly, the average length reported varied widely, with reported results ranging from 3.25 inches to 6 inches. Students were not required to report in specific units, and the provided rulers had both metric and English units. The instructions were left vague on purpose to foster a variety of results and encourage later discussion. This approach succeeded, as some teams accepted the task as an engineering challenge and worked hard to calculate error ranges and degrees of precision, while other teams were satisfied to find an answer online and submit their report quickly.

Table 2: Summary of student teams' project reports.

TEAM	# MEMBERS	MEASUREMENT METHOD(S)	# TUBES	# DATA POINTS	AVERAGE LENGTH REPORTED
1	4	Ruler	1	1	10.5 cm
2	4	Ruler	1	1	9 cm
7	4	Ruler	2	2	3.5 inches
10	4	Ruler	1	4	4 in
11	4	Ruler	1	2	10.2 cm
16	4	Ruler	2	2	10 cm ± 2%
17	4	Ruler	**Not Indicated**	8	10.3 ± 0.04 cm
19	4	Ruler	**Not Indicated**	1	8.9 cm
21	3	Ruler	18	18	10.62 cm
22	4	Ruler	15	15	5.87 in
23	4	Ruler	2	10	4 in
14	4	Ruler, Internet	0	4	11.12 cm
20	4	Ruler, Internet	2	3	4.03 in
24	3	Ruler, Internet	**Not Indicated**	11	12 cm
4	3	Internet	0	0	11.2 cm
12	4	Internet	0	0	4.5 in
15	4	Internet	0	4	4.5 in
3	4	Other	3	3	6 in
5	4	Other	4	8	9.925 cm
6	3	Other	0	0	5 inches
8	5	Other	3	9	12 cm
9	3	Other	1	1	9.2 cm
13	4	Other	4	4	3.25 in
18	4	**Not Indicated**	9	9	3.883 in

Debriefing and Discussion

When the 10 minute timer sounded and the final reports were collected, candy prizes were handed out to the members of the first team to submit a report and of the team that reported the most data points. A prize had also been offered for the team that submitted the most accurate result; however, there is no standard length for a toilet paper tube. Having done this exercise in various forums for more than 2 decades, the summer instructor (Dr. Katy Luchini-Colbry) knew that offering a prize for the most "accurate" answer would likely spark spirited debate and offer an opportunity for a deeper examination of the ethics of data collection, analysis and reporting. Indeed, several teams argued that their measurement or analysis techniques were superior, while other teams pointed to websites indicating that there was no industry standard for the length of a toilet paper tube. The instructor acknowledged that there was no "answer" against which the teams' results could be measured, and asked the students how they would like to resolve the situation. In the end, the students voted to distribute the remaining candy according to the order in which teams submitted their reports (so the second team got to pick first, followed by the third team, etc.).

There was not enough candy for everyone in the class, however, which led to a thoughtful discussion about the role of "prizes" in research settings. The instructor shared that the exercise had been framed as a "competition" and prizes had been offered as a way to tempt students to behave unethically. Although there did not appear to be cheating during the exercise itself, during the debriefing discussion the students could clearly identify the ways that teams could have cheated in order to win the prize for being the first to finish or the team with the largest number of data points. We then discussed parallels to scientific research, where the "prizes" include authorship, conference travel, winning grant proposals, building a research group, and achieving job security. Students compared this exercise to the ethics of larger research competitions, such as those sponsored by the XPrize Foundation[19] that seek to reward innovative solutions to grand challenges. We discussed the public nature of those research competitions, where the rules are freely available and the public is often invited to participate or observe the results, and how such transparency can encourage ethical behavior.

Another vibrant discussion during this debrief centered on the measurement methods used by various teams. Without identifying the specific team, the instructor read the reported methods out loud to the class for comment. Most teams had a straightforward approach involving measuring tubes with rulers or searching online for the answer. But some approaches sparked conversation: for instance, was it ethical to measure the same tube multiple times to increase the number of data points? Did it matter if the measurements were made by different team members, or with different rulers?

Students expressed strong opinions on both sides of these questions, and the instructor guided the discussion to consider the difference between how the measurements were made and how they were reported. For example, one team received a paper towel tube and had to decide how to handle that data point. According to their written report, they had assumed that a "toilet paper [tube was] 1/3 of paper towel" tube and so divided their measurement into 3 different data points. This approach generated some enthusiastic discussion among the students about the validity of those data and the usefulness of the approach—yet the instructor noted that these questions were about the scientific merit of the approach, not about team's research ethics. Indeed, the team had acted ethically by reporting their measurement methodology, thus allowing the readers to consider the validity of the underlying science.

This conversation proved to be an "aha!" moment for many students in the class, who expressed that they had never before considered that there was a difference between ethical behavior and quality scientific research. This simple, in-class exercise had clearly demonstrated that it was possible to act in an ethical manner (by reporting measurement methods and exclusion criteria) and still have other scientists disagree with your approach or results. The instructor summarized this to the class as one goal of good science: to provide enough detail to allow others to understand how the experiments were conducted, what data were collected, and how the results were obtained. Science benefits when your results can be replicated—or refuted—by others, and ethical standards require that researchers strive to accurately and truthfully convey the parameters of their work.

Following the debriefing, students worked in their small groups to review three case studies,[17] which are included in Appendix B. The first case was a scenario about suspected data fabrication. The second case study concerned authorship and giving appropriate credit for research contributions. The final case study examines the appropriate treatment of outlying data. While 10 minutes had been allocated in the original class design for a final large-group debrief of these cases, in practice the small-group discussions were both lively and lengthy and there was not sufficient time for a detailed large group conversation. The instructor did remain after class to provide more individual feedback, and these informal conversations indicated that students found the additional case studies interesting and helpful.

Concluding Remarks and Future Work

The exercise presented here was a fun, hands-on activity that scales well for a large group (94 participants). The focus was on one aspect of RCR—the ethics of collecting, analyzing and reporting data—and the resulting conversations helped students understand the overlap between behaving in an ethical manner and conducting high-quality scientific research. This ethics lesson evolved from an earlier exercise on accuracy and precision in scientific measurement, which has been used successfully with large and small groups of high school and college students, and as part of professional development activities for engineers and scientists. The EnSURE students who completed this exercise at MSU in 2015 found the experience to be an engaging and helpful way to explore some of the ethical considerations of data collection, and the instructor plans to continue offering the lesson in future EnSURE programs. This paper includes the handouts and case studies used in this summer program, and interested educators are encouraged to adapt them for their own use.

One challenge of conducting this seminar with nearly a hundred students is that scale does not lend itself to in-depth conversations about the case studies included in the appendix. Students did discuss the cases within their small groups, and were deeply engaged in these conversations—yet there was limited opportunity to reflect back on these conversations within the larger group. There was also no individual feedback or measurement of students' understanding of research ethics, or how this activity might influence their research practices. For Summer 2016, two options are being considered for additional reflection: one is having students discuss one or more of the case studies with their faculty research mentor, to get a sense of how the scenario might be handled within their disciplinary research area; a second is having students write a brief reflection statement about the ethics exercise and/or the case studies discussed in their small groups (or with their mentors). Several writing assignments are already required, as previously outlined in Table 1, so adding an ethics reflection may be a feasible option—and would allow the instructor to gauge students' individual understanding of the ethical issues discussed.

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Appendix A: Research Report Template

EnSURE Mini Research Competition Report

Team Name:

Members:

Research Methods:

Briefly outline the methodology you used to complete this research challenge.

Research Data:

Describe the data you analyzed as part of this research challenge.

Research Results:

Record the results of your work, and circle your team's final answer to this research challenge.

Appendix B: Ethics Case Study Handout

Ethics Case Studies

Case Study: Too Good to be True?

(from Branchaw, Pfund and Rediske (2010) Entering Research: A Facilitator's Manual. W.H. Freeman & Co, New York. p. 187.)

Evelyn and John joined the lab at the same time as sophomores and have been doing research on related, yet separate projects for the past year. Evelyn, a quiet and very diligent worker, spends many hours in the lab working on her project. She has encountered several obstacles in her research, but is making slow, yet consistent progress. She sees John there infrequently and notices that he spends most of his time chatting with the other lab members. The PI of the lab travels a lot, but when he is there, John always seems to connect with him.

At lab meeting last week, John presented his research. The results he reported were exactly what the PI was looking for. The PI was ecstatic. Evelyn was stunned. She does not remember seeing John do any of the experiments he presented. She suspects that he is not being truthful, but has no proof. His research is linked to hers, so if the results are not valid, it will negatively impact her project, and the entire lab. Everyone really likes John, including the PI, and everyone knows that she has been dealing with a lot of setbacks in her research. She doesn't want to look like a jealous co-worker by accusing John of fabricating data, but she truly suspects that he has.

1. What should Evelyn do?
2. Why is misconduct such an important issue in the scientific community?
3. What measures are in place to help prevent misconduct?

Case Study: Credit Where Credit is Due

(from Branchaw, Pfund and Rediske (2010) Entering Research: A Facilitator's Manual. W.H. Freeman & Co, New York. pp. 199. Their original source is "On Being a Scientist: Responsible Conduct in Research," 2nd ed., National Academy Press, 1995)

Bea, a junior, was working on a research project that focused on developing a new experimental technique. To present her work at the Undergraduate Symposium, she prepared a poster outlining her new technique. During the poster session, Bea was surprised and pleased when Dr. Freeman, a leading researcher on campus, engaged her in a conversation. Dr. Freeman asked extensively about the new technique, and she described it fully, happy to be confidently discussing her work with a fellow scientist. Bea's faculty advisor had encouraged his students to openly share their research with other researchers, and Bea was flattered that Dr. Freeman was so interested in her work.

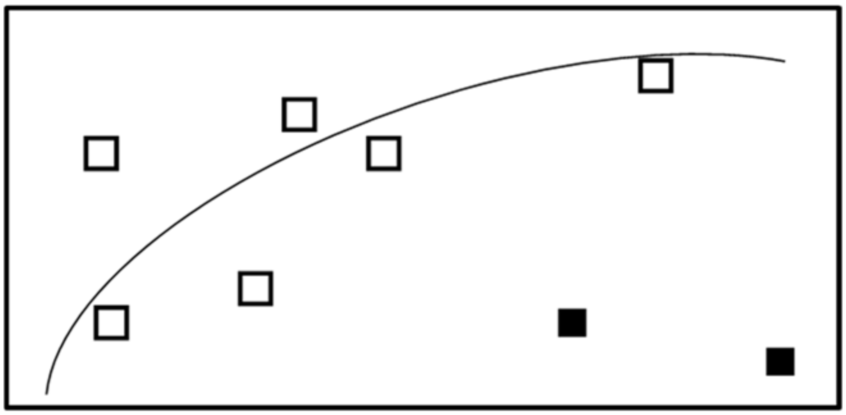
Six months later Bea was leafing through a journal when she noticed an article by Dr. Freeman. The article described an experiment that clearly depended on the technique that Bea had developed. She did not mind, in fact, she was somewhat flattered that her technique so strongly influenced Dr. Freeman's work. But when she turned to the citations, expecting to see a reference to her abstract or poster, her name was nowhere to be found.

1. Does Bea have any way of receiving credit for her work?
2. Should she contact Dr. Freeman in an effort to have her work recognized?
3. Is Bea's faculty advisor mistaken in encouraging his students to be open about their work?

Case Study: The Selection of Data

(from Branchaw, Pfund and Rediske (2010) Entering Research: A Facilitator's Manual. W.H. Freeman & Co, New York. pp. 194-5. Their original source is "On Being a Scientist: Responsible Conduct in Research," 2nd ed., National Academy Press, 1995)

Seniors Deborah and Kathleen have made a series of measurements on a new experimental semiconductor material using an expensive neutron sources at a national laboratory. When they get back to their own lab and examine the data, they get the following data points. A newly proposed theory predicts results indicated by the curve.



During the measurements at the national laboratory, Deborah and Kathleen observed that there were power fluctuations they could not control or predict. Furthermore, they discussed their work with another group doing similar experiments, and they knew that the group had gotten results confirming the theoretical prediction and was writing a manuscript describing their results. In writing up their own results for their senior research project and hopefully for publication, Kathleen suggests dropping the two anomalous data points near the abscissa (the solid squares) from the published graph and from the statistical analysis. She proposes that the existence of the data points be mentioned in the paper as possibly due to power fluctuations and being outside the expected standard deviation calculated from the remaining data points. "These two runs," she argues to Deborah, "were obviously wrong."

1. How should the data from the two suspected runs be handled?
2. Should the data be included in tests of statistical significance and why/why not?
3. What sources of information could Kathleen and Deborah use to help decide?