

## Teacher Version: Who is the Most Accurate Researcher?\*

**Purpose:** For students to discover the nature of random and systematic errors found in physical measurements.

**Procedure:** Divide the class into three laboratory teams: Alpha, Beta, and Omega. The teams will compete for the title of the world's most accurate researcher. Each team chooses a laboratory director. Each team's director is given a letter containing the setup for the activity and general instructions. The director reads the letter to their team and explains the contest procedure. After all the students have understood the objectives, they proceed to make measurements.

Each student receives identical drawings of the elliptical orbit of planet "Gamma." However, the paper rulers provided to each group are not identical. **Do not tell the students beforehand that their rulers are not the same and make sure the groups do not communicate with each other.** Group A's rulers are enlarged 105% of their actual size, Group B's rulers are reduced to 95% of their actual size, and Group C's rulers are their actual size. Make sure you prepare enough rulers for all the students.

Each student measures the major and minor axes of the orbit of "Gamma" and records the result to the nearest whole millimeter on their data sheet. When finished, the director collects the measurements, and the group finds the average for the major and minor axes, and calculates the eccentricity. Each director reports the laboratory's measurements (a table can be drawn on the board).

**Results and Analysis:** Group A will report measurements that are smaller than groups B and C. Group B will report measurements larger than Groups A and C. Group C will report measurements that fall between those reported by Groups A and B. However, the random error cancels out in the eccentricity calculation. Thus, the eccentricities calculated by all three groups should be similar.

Because each team used a different ruler, they will see systematic and random errors in their results. Teachers should let students discover the reason for the

\*Note: This activity was modified from "The Orbit of Planet Gamma". Go to <http://www.ieee.org/web/education/preuniversity/tispt/lgamma.html> for the updated version.

differences in the measurements when groups compare their results with each other. Students should also notice the consistent differences between the measurements. However, they see that calculated eccentricities are similar. If students don't, point it out. Ask the class to explain from the data why the eccentricities are the same while the major and minor axes measurements vary from one group to another.

**Typical student data:**

|                       | Group A    |            |       | Group B    |            |       | Group C    |            |       |
|-----------------------|------------|------------|-------|------------|------------|-------|------------|------------|-------|
|                       | Major Axis | Minor Axis | $e$   | Major Axis | Minor Axis | $e$   | Major Axis | Minor Axis | $e$   |
| <b>Measurement 1</b>  | 221        | 140        | 0.774 | 250        | 160        | 0.768 | 238        | 152        | 0.769 |
| <b>Measurement 2</b>  | 228        | 144        | 0.775 | 250        | 160        | 0.768 | 239        | 152        | 0.722 |
| <b>Measurement 3</b>  | 227        | 145        | 0.769 | 251        | 150        | 0.802 | 238        | 152        | 0.769 |
| <b>Measurement 4</b>  | 227        | 144        | 0.773 | 254        | 160        | 0.777 | 238        | 151        | 0.773 |
| <b>Measurement 5</b>  | 227        | 144        | 0.773 | 251        | 160        | 0.770 | 237        | 151        | 0.771 |
| <b>Measurement 6</b>  | 227        | 140        | 0.787 | 250        | 160        | 0.768 | 237        | 152        | 0.767 |
| <b>Measurement 7</b>  | 227        | 145        | 0.769 | 251        | 150        | 0.802 | 238        | 152        | 0.769 |
| <b>Measurement 8</b>  | 227        | 144        | 0.773 | 254        | 160        | 0.777 | 238        | 151        | 0.773 |
| <b>Measurement 9</b>  | 227        | 144        | 0.773 | 251        | 160        | 0.770 | 237        | 151        | 0.771 |
| <b>Measurement 10</b> | 227        | 140        | 0.787 | 250        | 160        | 0.768 | 237        | 152        | 0.767 |
| <b>Average</b>        | 227        | 143        | 0.775 | 251        | 158        | 0.777 | 238        | 152        | 0.770 |
| <b>Minimum</b>        | 221        | 140        | 0.769 | 250        | 150        | 0.768 | 237        | 151        | 0.767 |
| <b>Maximum</b>        | 228        | 145        | 0.787 | 254        | 160        | 0.802 | 239        | 152        | 0.773 |

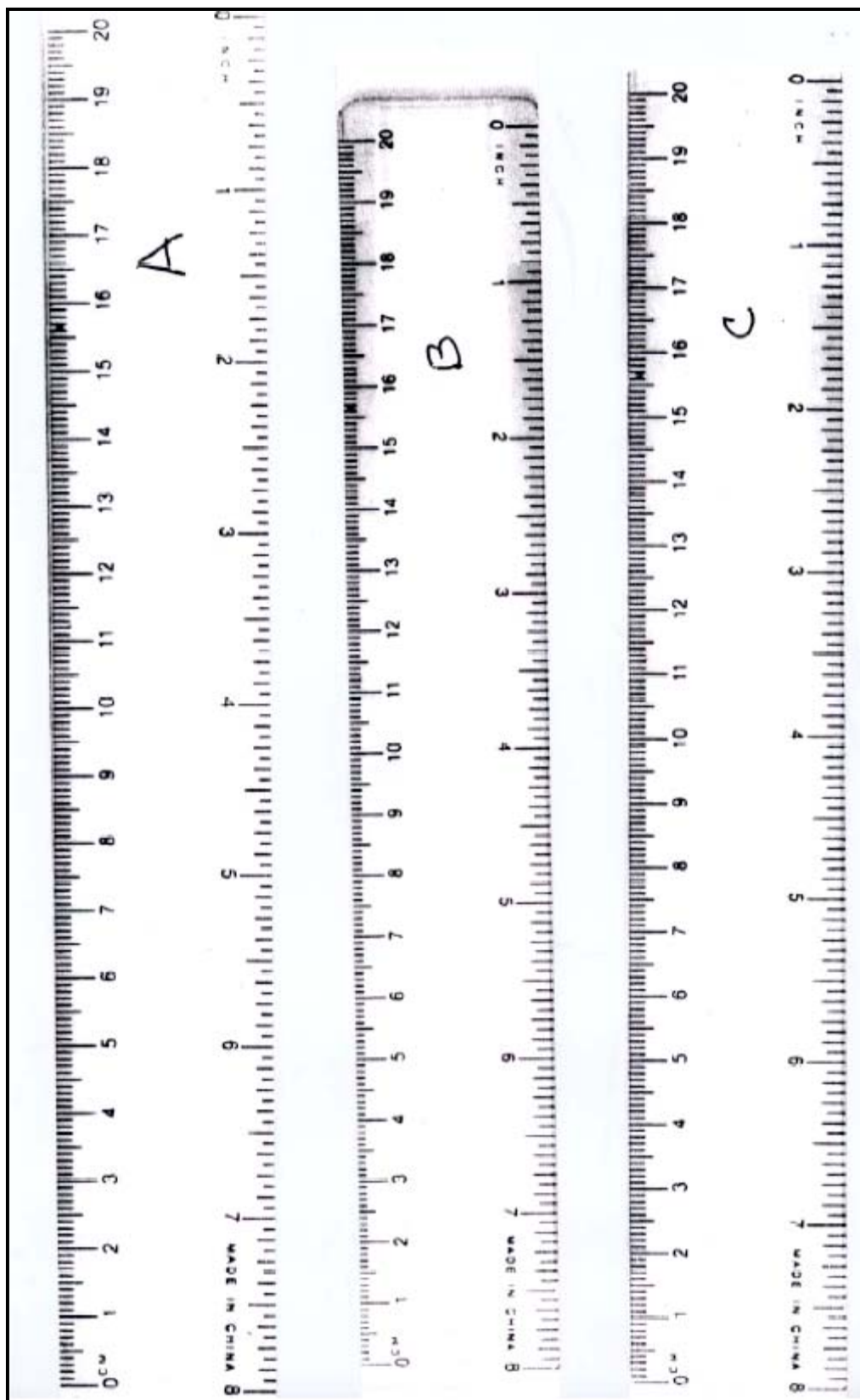
**Student Report:** Students will answer the following questions:

1. Does the data from group A show signs of random error? How about the data from groups B and C? Explain your answers.
2. a) Which group has the least variation among their measurements of the major axis?  
 b) Which group has the least variation among their measurements of the minor axis?  
 c) What does this imply about the skill of the researchers in each group?

3.
  - a) Is any group consistently high or low in their measurements of the major axis compared to the other groups?
  - b) Is any group consistently high or low in their measurements of the minor axis compared to the other groups?
  - c) What type of error, random or systematic, might account for this? Explain your answer.
4. Do the calculated eccentricities of one group show the same variation when compared to the values for eccentricity calculated by other groups that was noted for the major axis and minor axis data? What might account for this?
5. Define random error in your own words.
6. Define systematic error in your own words.
7.
  - a) Do systematic errors tend to "average out" over many observations?
  - b) Do random errors tend to "average out" over many observations?
8. Which of the three laboratories, A, B or C deserves recognition as the most accurate and advanced researchers in the world? Defend your answer.

**Post-Lab Discussion:** Lead the class in a discussion about the differences in the reported results found in the table. First tell them that research laboratory is located in a different part of the world and that the rulers represent test equipment that cannot be moved from one place to another. Ask them to propose reasons for the differences among the results of the three groups. After the discussion, ask what criteria should be used for the title of the world's most accurate researcher. Finally have the class vote on which team deserves the recognition.

Paper Rulers



## Letter to director of the Research Laboratory

You are the director of one of three international research laboratories that are competing for global funding, possible Nobel prizes, and bragging rights as the most accurate and advanced group of researchers in the world. Because of the rivalries among the three laboratories, each laboratory maintains a policy of strict secrecy and never shares preliminary results with the other two laboratories.

Raw data from a space telescope has been provided to all three research laboratories in the form of scale drawings of the orbit of planet Gamma. Each research laboratory is charged with measuring the major axis and the minor axis of the orbit and calculating the eccentricity of the orbit.

As the director, you have decided that it is best that each researcher of your team to work independently and at the end the results will be averaged. Averaging the data should eliminate random error so that the results from your laboratory will be the most accurate in the world. Unfortunately, one *former* disgruntled member of your laboratory has leaked your averaging technique to the other groups, which have also decided to have their researchers work independently and then average the results to reduce the effects of random error.

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**NAME OF THE RESEARCH LABORATORY:** \_\_\_\_\_

### RESULTS

**Minor axis:**

Minimum \_\_\_\_\_      Maximum \_\_\_\_\_      Average \_\_\_\_\_

**Major axis:**

Minimum \_\_\_\_\_      Maximum \_\_\_\_\_      Average \_\_\_\_\_

**Eccentricity:**

Minimum \_\_\_\_\_      Maximum \_\_\_\_\_      Average \_\_\_\_\_

