**Is Measuring an Art or a Science**
**What is "to measure"? Accuracy and precision in nano-measurements**

## Introduction:

Measurements are part of our everyday life, but have we stopped to think about what "to measure" means? When we measure, we actually compare a magnitude (length, weight, etc.) with a standard accepted to be the measuring unit. This comparison implies to count how many times this measuring unit fits our object being measured. To measure implies to compare and read a scale.

When performing engineering and scientific measurements we need to understand that they are not perfect. These imperfections can be described by the accuracy and precision of the measurement. Only after understanding the errors associated with the instrumentation used, the methods of measurement, etc. reliable and reproducible data can be attained.

Nanotechnology occurs on the scale of 1-100 nanometers (in one direction). There have been numerous predictions about the growth in nanotechnology production and its impact on manufacturing in the near future. Manufacturing and commercial exchange of nano products will create a need for high-quality measurement technology because manufacturers must ensure that components from different sources will fit together.

## Objectives:

1) To understand the difference between accuracy and precision in nanoscale measurements.
2) To understand the difference in the accuracy and precision in macroscale measurements and nanoscale measurements.

## Materials:

- 1 squares template
- 1 circle template
- 4 rulers
- Index of Refraction Plate

## Procedure:

### Part I

A. Highlight or circle 10 squares in the squares template
Using the ruler calculate the length of the squares
Record your answer in the data table below
Repeat with other rulers
Find the average for each column



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B. Highlight or circle 10 circles in the circles template
Using the ruler calculate the diameter of the circles
Record your answer in the data table below
Repeat with other rulers
Find the average for each column

C. Answer the questions in the conclusion section

**Part II**

Now place the refraction plate over the squares template and the circles template to complete the activity.

D. Using the ruler, calculate the length of the squares you highlighted before
Record your answer in the data table below
Repeat with other rulers
Find the average for each column

E. Using the ruler calculate the diameter of the circles you highlighted before
Record your answer in the data table below
Repeat with other rulers
Find the average for each column

F. Answer the questions in the conclusion section.

**Analysis:**

**Part I**

Square length results

| | Ruler 1 | Ruler 2 | Ruler 3 | Ruler 4 |
|---|---|---|---|---|
| Sample # | length (mm) | length (mm) | length (mm) | length (mm) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| Average | | | | |



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Circle diameter results

| | Ruler 1 | Ruler 2 | Ruler 3 | Ruler 4 |
|---|---|---|---|---|
| Sample # | diameter (mm) | diameter (mm) | diameter (mm) | diameter (mm) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| Average | | | | |

**Part II**

Square length results

| | Ruler 1 | Ruler 2 | Ruler 3 | Ruler 4 |
|---|---|---|---|---|
| Sample # | length (mm) | length (mm) | length (mm) | length (mm) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| Average | | | | |

Circle diameter results

| | Ruler 1 | Ruler 2 | Ruler 3 | Ruler 4 |
|---|---|---|---|---|
| Sample # | diameter (mm) | diameter (mm) | diameter (mm) | diameter (mm) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| Average | | | | |



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## Conclusion

I) Now that you know the average size of your figures, use this information to answer the following questions:

For the squares in Part I

1) Which measurement average is the most accurate?
2) Which measurement average is the most precise?
3) Which measurement average has the greatest Error?
4) Which measurement average has the greatest uncertainty?

For the circles in Part I

5) Which measurement average is the most accurate?
6) Which measurement average is the most precise?
7) Which measurement average has the greatest Error?
8) Which measurement average has the greatest uncertainty?

Let's assume that you receive a report from a very reputable lab that certifies the squares are 28.0 mm long and that the circle diameters are 30.0 mm. Answer the following questions:

For the squares in Part I

1) Which measurement average has the least accurate measurement?
2) Which measurement average is the least precise?
3) Which measurement average has the smallest Error?
4) Which measurement average has the smallest uncertainty?

For the circles in Part I

5) Which measurement average has the least accurate measurement?
6) Which measurement average is the least precise?
7) Which measurement average has the smallest Error?
8) Which measurement average has the smallest uncertainty?

II) What happened with the accuracy and precision of your measurements when you place the high refractive index plastic on top of the template?

III) Explain why the measurements with the plastic and without it change. Are we measuring the same property?

IV) Do some research about the gold nano-particle sizes NIST references (Reference Material 8011, 8012, and 8013) Explain in your own words which measurements reported these reference materials are the most accurate and the most precise and why you got to this conclusion.
NIST Reference Materials on Gold Nanoparticles:

- https://srmors.nist.gov/view_detail.cfm?srm=8011
- https://srmors.nist.gov/view_detail.cfm?srm=8012
- https://srmors.nist.gov/view_detail.cfm?srm=8013



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