3. Pasta on the table

Experience showing where measurement errors come from. The action is aimed at drawing attention to errors that may occur during measurements performed under the same conditions with different sensors.

Keywords: metrology (measurements), measurement errors, accuracy of measuring tools, measurement statistics, distribution of quantities

Materials outside the box

- school desk (or A4 sheet for remote work)
- various instruments for measuring lengths: school rulers of different lengths, metal pull-out ruler,
- folding carpenter's ruler, tape measure, tailor's measure
- note-taking materials (possibly a running spreadsheet)
- calculator
- a packet of pasta (e.g. tubes cut at right angles, drills, short threads, etc.)

Research questions and experiments

1. What affects the results of measurements of the length of the school desk (diagonal A4 sheet)?

The course of the experiment

1. We share measuring tools in a group of 4 people, so that everyone has a different tool.
2. We measure the length of the same bench (diagonal A4 sheet) using the selected tool.
3. The obtained measurement results are recorded and compared with each other.
4. On the selected measuring tool, we try to find the marking informing about the accuracy class .

Questions about observations

Do the results of measurements of the length of the bench (diagonal A4 sheet) differ?
What measuring tools were used to take the measurements?
Did the use of the same tool by people from different groups give the same result?

2. With what accuracy were the pieces of pasta made?

The course of the experiment

1. We share measuring tools in a group so that everyone has a different tool.
2. Sprinkle about 100-200 g of pasta on the table.
3. Using a school ruler, we measure the lengths of 20 pieces of pasta selected at random.
4. After measuring, we put each piece aside.
5. The results of the measurements are recorded in the table.
6. Data from the table is transferred to the graph – we create a histogram (e.g. the height of three boxes on the chart is the number of three pieces of pasta of a given length).

Questions about observations

Is each piece of pasta the same length?
Which lengths are the most and which are the least?

Expected result

The results of measurements of the length of the bench (diagonal A4 sheet) are likely to diverge due to the use of different tools and measurement techniques. In the case of pasta measurements, the sizes may differ due to factory differences.

What can go wrong and how to deal with it

There are no discrepancies in the measurement results.
The smaller the things we measure and the less accurate the tool we do, the more likely it is that the results will mostly be the same. To obtain divergent measurement results, use a more accurate tool or increase the measured length (e.g. measure the length of a room or a sheet of A3 paper).

There are too many discrepancies in the measurement results.
To avoid this, everyone should measure the same object (e.g. bench/room, A4/A3 sheet of paper).

Explanation of the observed phenomenon

The first part of the experiment, concerning the measurement of the length of a bench or diagonal of an A4 sheet, shows that both the selection of a tool with a specific accuracy class and its correct use allow to minimize some errors. In short, it can be assumed that the following types of errors may have occurred in the measurements of the length of the bench (diagonal of the A4 sheet):

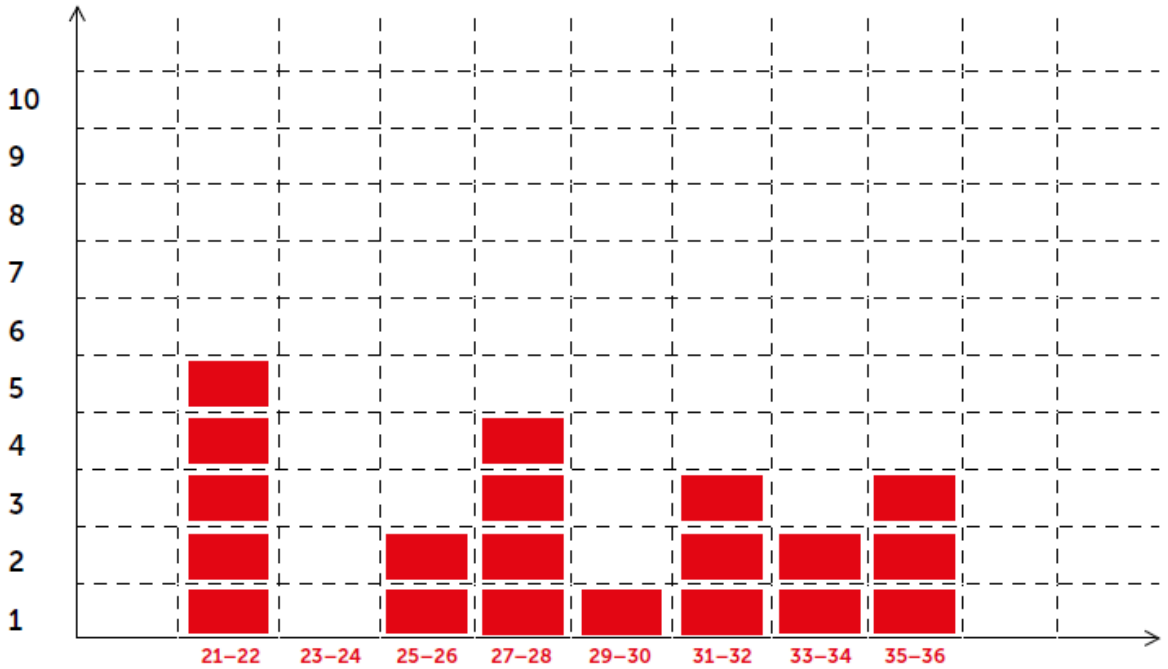
- "thick" errors – resulting from inattention, lack of focus (e.g. incorrect reading, moving the ruler on the measured surface, using a scale in inches instead of a scale in cm, etc.);
- systematic errors – resulting from the design of the tool or the adopted measurement technique (e.g. too strong stretching of the tape measure);
- accidental errors – caused by external factors (e.g. the influence of temperature on the length of the ruler) or situational (e.g. parallax – incorrect reading of the result due to improper positioning of the eye relative to the scale on the ruler).

These errors can be minimized by repeating the measurements repeatedly.

The measurements carried out in the first part of the experiment are intended to make students aware that by using different tools, they can obtain different results. In the world of scientific research, this is normal. When we answer the question of what and how influenced the results of our measurements, we will learn how to more accurately measure the tested object, avoiding or minimizing possible errors.

Will this determine the actual length of the bench? Not really. We will only give its approximate, maximum probable length, taking into account the sum of possible errors.

The second part of the experiment shows that we are not measuring a pattern, but specific objects belonging to the same category, each of which may have slightly different dimensions. In this way, we only statistically present the probability of the occurrence of objects with given dimensions within a given category. Pasta length measurements are methodologically closer to quantitative measurement statistics and size distribution statistics and better reflect measurements of the amount and size of particulate matter. It should be noted that in the measurements of pasta made by one person and using only one tool, the differences in the length of individual pieces of pasta are significantly greater than the differences in length recorded when measuring the bench (A4 sheets). The former result from the size spread in the production of pasta (it can have any dimensions), while the latter result from the properties of the measuring tool (because a school desk or A4 sheet must have certain dimensions). Both categories of differences illustrate the types of measurement errors that may occur when measuring particulate matter. The school ruler here symbolizes the dust sensor, while the pieces of pasta correspond to particles of particulate matter of a wide spectrum of size.



y: number of pieces of pasta

x: pasta length [mm]

Fig. 1. Sample histogram showing measurement results

Observed phenomenon and air pollution

In nature, only the most commonly measured dust sizes – 2.5 and 10 micrometers (µm) – do not occur. In the air there are particles of pollutants of various intermediate quantities (e.g. 1.80, 2.65 or 3.48 µm, etc.). This means that when choosing a range of 2.5 µm (or 10 µm), we specify a specific size range particles of impurities that we want to capture by the sensor, i.e. particles of 2.5 µm (or 10 µm) and smaller. The method of feeding the result is included in an algorithm integrated with the sensor designed by the equipment manufacturer. Usually, we do not have knowledge about how a given device averages the measurement results, but in the end, we always get an average value, taking into account significant deviations and as close as possible to the actual value. With a similar situation we have to doing in our experience: among the measured pieces of pasta outside the length e.g. approx. 2.5 cm may occur smaller – e.g. 2.3 cm or 1.8 cm long. measurements of both types of objects (pasta, particulate matter), we always give only a statistical number pieces of pasta of a certain length (e.g. up to approx. 2.5 cm) and particles of particulate matter of selected size (e.g. up to approx. 2.5 µm or up to approx. 10 µm).