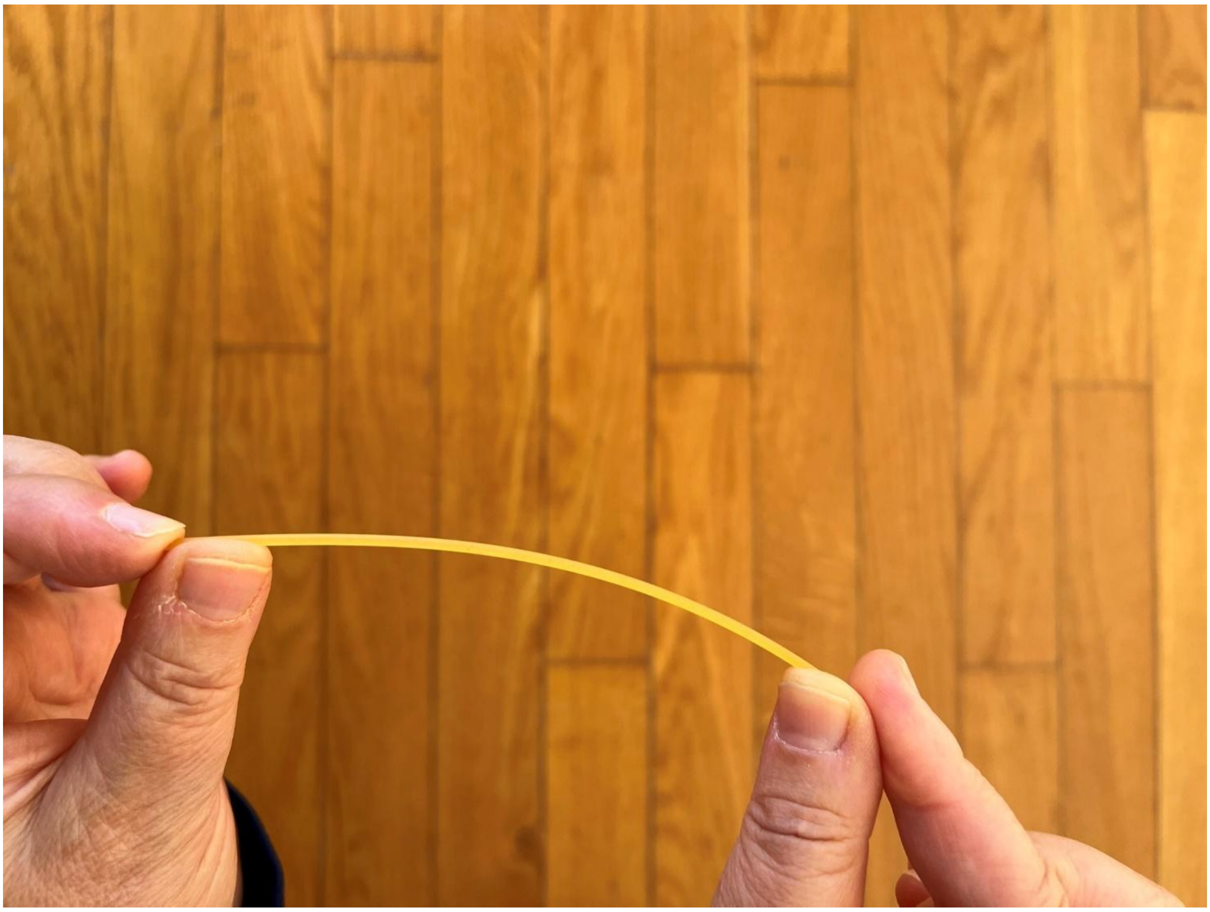
NON-TRADITIONAL MEASUREMENTS AND THE MEASURING PROCEDURE

STUDENTS MEASURE A RANGE OF UNUSUAL PROPERTIES OF MATERIALS

Mojca Čepič, Ana Gostinčar Blagotinšek

University of Ljubljana, Faculty of Education, Slovenia



Co-funded by the Erasmus+ Programme of the European Union

SUITABLE FOR AGE(S)	SUBJECT(S)	KEY FOCUS
12-19+ years	Physics, Mathematics	Measurement

INTRODUCTION

This task introduces measuring procedures. By the time students reach lower secondary level, they have already learned to measure time, length, mass, and temperature - both in school and in everyday life. Because these procedures are so familiar, students are often not motivated to learn about measurement when standard examples are used.

Yet when physics is introduced, topics such as measurement, precision, and error are usually covered at the very beginning, traditionally with familiar examples. Moreover, why a measuring procedure has well-defined steps that must be strictly followed is almost never discussed. The goal of this task is to introduce the concept of a measuring procedure through non-standard examples.

Every physics curriculum starts with measurement because physics is an experimental science. Standard measurements are also encountered in mathematics. Instead of repeating measurements that students already know, it is more motivating to explore non-standard properties, helping students see the importance of strictly equal procedures for comparing results.

This task is especially useful at the start of the school year, during early physics classes. It can also be used when transitioning from lower to upper secondary school, as it encourages social interaction, collaboration, and helps students get to know new peers and a new teacher.

TASK DESCRIPTION

This task introduces semi-quantitative comparison and teaches students to develop procedures that enable assigning a numerical value to properties of objects or phenomena. While most measurements are standardised, this task helps students understand the underlying procedure using non-standard examples.

The focus is on designing a measuring procedure, not simply collecting data. Students experience firsthand why a measuring procedure must be well-defined to allow for valid comparison across groups and contexts.

This task introduces the requirements of a good measuring procedure by using non-standard properties. It comprises two activities

1. How Brittle Are Spaghettis?
2. Which Colour Should You Wear in Fog?

The first activity, which involves measuring the brittleness of spaghetti, demonstrates how even everyday objects, such as spaghetti, can reveal complex scientific concepts about materials, measurement, variability, and the importance of a well-defined process in science. The second activity, based on the visibility of colours in fog, helps students understand that visibility is not just a scientific idea; it's a real-life safety concern. Understanding how colours behave in different environments helps us make better choices and stay safe.

This rich task is best described as a guided inquiry. However, its main goal is not to answer a specific question, but rather to design a procedure that allows for comparing properties of different types of spaghetti and colours.

TASK PREPARATION

Students work in groups of three or four. Random assignment (e.g. drawing cards) is recommended to promote collaboration.

In addition to different types of spaghetti, some school laboratory equipment is needed, like weights, dynamometers, kitchen scales, supports in the form of wooden blocks and similar for the first, and coloured paper, paus paper or any other semi-transparent paper. Teachers should also be responsive to students' ideas, as new solutions may emerge requiring additional equipment.

Materials needed:

For activity 1 (Brittleness of spaghetti):

- 10–15 uncooked spaghetti strands from at least three different types or brands (Differences may include thickness, egg content, flour type, or producer).
- Spare spaghetti of each type for additional trials
- Dynamometers
- Kitchen scales
- Adhesive tape
- Wooden blocks
- Weights (1 g, 2 g, 5 g, 10 g, 20 g, 50 g, etc.)
- Smartphones or tablets (to record video of measurements)

For activity 2 (Visibility of colours):

- Coloured paper (2 A5 or A6 pieces of paper with different colours. Elementary colours should be available, but also white, grey and black).
- Paus paper or any semi-transparent paper (in A6 pieces, at least 20 per group)
- Optional advanced setups (triangular wedge, milky water in aquarium, described in the activity).
- Scissors

TASK IMPLEMENTATION

Activity 1: How Brittle Are Spaghettis?

Introduction: Begin with a short discussion:

Everyone knows that uncooked spaghetti breaks easily, but are all spaghettis equally brittle? What if you were packing spaghetti for a camping trip—would it matter if it broke easily? Today's goal is to compare the brittleness of different types of spaghetti, and to develop a measurement procedure to do so.

Procedure

For this activity, ten to fifteen strands of spaghetti from at least three different types are needed. These types refer to spaghetti produced by different manufacturers, with varying egg content, flour types, and thicknesses. Precise control of these variables isn't crucial at this stage, as the primary goal is to develop a method for comparing and measuring brittleness. Ensure that extra spaghetti from each type is on hand. Half-kilogram packages are more than sufficient.

The teacher forms random groups of three or four students. Each group is given 15 spaghettis of each type. The goal is to determine which spaghetti is most brittle, and to rank the rest from most brittle to least brittle.

It is advised to prepare in advance bundles of spaghetti with names and origins, for example, No. 3 Barilla. Alternatively, students can be asked to collect spaghetti from packages and they mark them in one way or another to know which is which.

Process:

- Students typically begin by breaking spaghetti by hand. They quickly realise that this method is inconsistent for comparing the brittleness of the spaghetti. Therefore, a procedure must be agreed upon.
- Students are asked to propose more systematic methods. They usually come with ideas such as
    - Hanging weights on spaghetti supported between two blocks
    - Pulling with a dynamometer until the spaghetti breaks
    - Using a kitchen scale to measure the force needed to break a single spaghetti by pressing down on it or by placing the spaghetti between two scales as supports and breaking it by applying pressure with a finger (Figure 1).

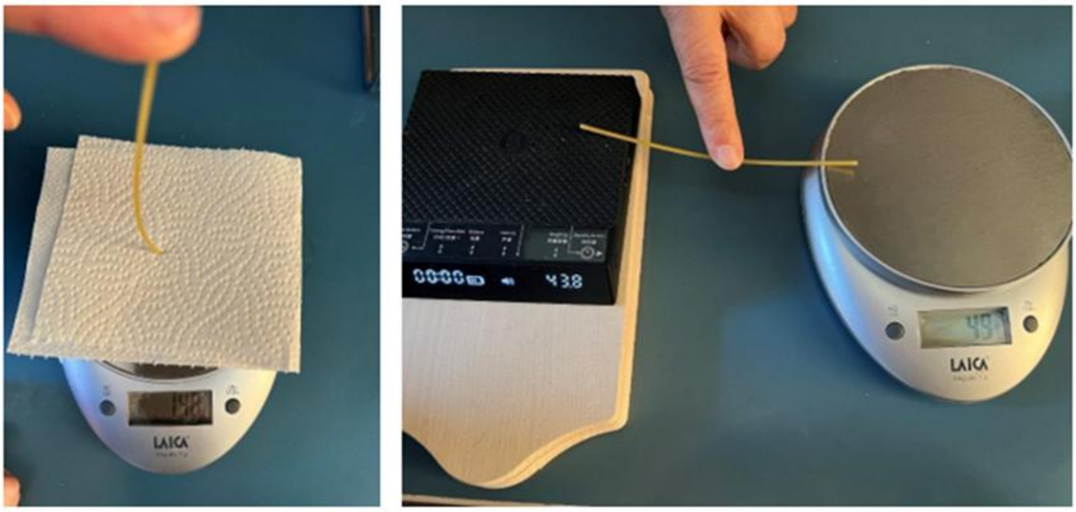


Figure 1. Two methods of measuring brittleness. The left one yields a much larger value.

Any of these methods allows for sorting the spaghetti from the least to the most brittle. However, to sort accurately, students must agree on the process; for example, if they use two supports, the length of the spaghetti in the air should always be the same, and weights should be hung at the same positions, such as always in the middle. If the process remains consistent, the results are comparable. But what exactly are these results? Students typically measure the force needed to break the spaghetti. This force can be measured by the weight the spaghetti carries, the pressure it withstands, or by a dynamometer pull. While hanging a weight is a static measurement—gradually increasing until the spaghetti breaks—the challenge lies in accurately relating the force needed for breakage to readings from a dynamometer or a kitchen scale.

Students may film the measurement with mobile phones to capture the precise breaking force.

Discussion points:

Do repeated measurements yield the same result?

In typical simple measurements, such as measuring the length of different tables in the classroom, there is usually little variation between measurements. However, spaghetti are not products where brittleness needs to be identical for each one. Therefore, some variation in the force measurements is expected. Multiple measurements are necessary to estimate a representative brittleness value for a particular type of spaghetti.

Are measurements of different groups comparable?

At this point, a discussion on how to make more measurements easier and faster is necessary. If different groups have developed different approaches to ordering spaghetti, then their results cannot be compared. However, if all groups agree on the same procedure, including all its details, they can compare their results. Additionally, when work is distributed, it becomes much less demanding to measure ten pieces of spaghetti of the same type. By first using the same procedure, recording results in a shared table—on a common computer or in a document accessible to everyone, such as Google Docs—then collectively performing 100 measurements for each type of spaghetti in ten or twenty minutes becomes feasible. These collected measurements

Co-funded by the
Erasmus+ Programme
of the European Union

can then be used to calculate averages, errors, distributions, and all other important parameters in any serious scientific investigation measurement.

The teacher should stress that students have developed a measuring procedure that yields a value—such as force—that reflects the property being studied, namely the brittleness of a particular spaghetti type. This value is obtained from multiple measurements and offers an estimate of the range where a single measurement is likely to fall. However, the average brittleness can still be compared across different spaghetti types, allowing them to be ranked from least to most brittle or vice versa.

Outcome:

The main conclusions of this activity are:

a) It is possible to compare several non-standard properties of different objects and phenomena.

b) When comparing these properties, one can usually determine whether the properties of two objects or phenomena are equal, although not always.

c) In cases where they are not equal, it is often possible to decide whether one object or phenomenon has a "bigger" or "smaller" property than the other, and to order them accordingly.

d) To determine equality or inequality, a specific process must be followed.

e) Often, this process also produces a numerical value or can be adapted to do so.

f) If everyone follows the same steps in this process, they will reach the same conclusions regarding the order of objects or phenomena and the numerical value associated with the property, when applicable.

The entire procedure, including all detailed steps that assign a number to a property, is known as the measuring procedure. When the measuring procedure is agreed upon, the inquiry could be developed into a project on inquiry, which properties affect brittleness.

Activity 2: Which Colour Should You Wear in Fog?

In this activity, students explore the visibility of colours in fog. This example of inquiry revolves around a common safety concern in traffic: which clothing colour is most visible in fog? Although this question appears in textbooks at various levels, it often lacks an activity that allows students to discover the answer themselves. Typically, only the fact is provided that yellow is the most visible colour. However, the correct answer is more complex; optimal visibility depends not only on the clothing colour but also on the environment, specifically, how well the clothing colour contrasts with the surroundings.

The aim of this activity is for students to realise that the colour of clothing in fog or darkness affects visibility, and that more visible objects are easier for drivers to recognise, making people in more visible clothes safer. The primary goal of the activity is to design a method for comparing visibility that can be applied to various conditions, including visibility in darkness and in contrasting situations.

This activity requires group work and promotes social interactions and collaboration. As materials for experimentation are easily accessible, it is advisable to form smaller groups, such as two or three students per group, although individual work is also possible.

For lower secondary school, the background papers and the "clothes" papers can be prepared in advance. For the background, coloured pieces of paper in A6 size are used. To test visibility, the model of clothes is printed and cut out of paper circles of different colours, each with a perimeter of about 2 to 3 cm.

Brainstorming:

The activity begins with questions about traffic safety and the different roles people may have, such as pedestrians, cyclists, motorcyclists, drivers, or even professional drivers of buses or other vehicles who must drive for many hours without breaks. For example,

- How could a pedestrian help the driver spot them more easily when they share the common path?
- What colours of clothes should one wear in fog and darkness?
- What other tools can one use to enhance one's own visibility?

The teacher explains that the experiment will focus on testing which colours are most visible in fog-like conditions. Students are asked to suggest a method for finding the colour that is most visible in fog through an experiment. Answers vary, but students seldom suggest taking a piece of paper with a distinctive colour and going away from an observer. Usually, distances should be too large to really show the difference, but if pieces of paper are too small other optical phenomena like diffraction prevent clear conclusions.

The teacher prompts students to consider different ways to create a fog model. Several options are available: using semi-transparent paper like paus, other very thin papers, or opaque adhesive tape such as Scott tape. The number of layers at which the colour can no longer be distinguished serves as a measure of visibility. Transparent sheets can also be used, and if stacked in sufficient quantity, absorption becomes significant and hinders colour recognition.

The measuring procedure must consider the observer's eyesight, as visibility relies on human vision. Therefore, students should agree on a procedure where one person knows the colour because they set up the experiment, but the person attempting to identify the colour does not. Alternatively, all students involved in the experiment could know the colour in advance. However, in this case, the situation—where they are supposed not to recognise it—is always influenced by prior knowledge.

Step-by-Step Instructions

Divide students into groups of three (Students A, B, C).

- Student A selects the colour, picks a matching piece of paper, and covers it with several transparent sheets until the colour becomes indistinguishable. The student notes the colour and the number of pages, then adds two or three extra layers for accuracy. Finally, they record the total number of sheets used.
- Students B and C observe the pile of papers covering the coloured piece from a perpendicular position at a distance of between half a metre and one metre.

For instance, student A places the pile on a chair, while students B and C stand by the chair to observe.

- ➢ A removes sheets of paper one by one until either B, C, or both fail to identify the colour. The total number of sheets removed is recorded, and the number of sheets covering the coloured area is then calculated. A removes an additional layer, and B and C determine whether the initial colour identification was correct. The number of layers covering the paper when the colour is first identified serves as the measure of visibility.
- ➢ The procedure is repeated for additional colours, with the roles of A, B, and C interchanged. Notes specify the triad, the colour, the observer (A, B, or C), and the number of layers.
- ➢ Each group orders colours based on visibility and notes the number of layers as a measure of visibility.

If the whole class used the same methodology, their results can be directly compared. Often, results reveal that the number of layers differs slightly, even when the area of the piece and the artificial fog created from layers of opaque paper are equal. There are at least two reasons for these discrepancies: either human eyes do not perceive colours equally, or the lighting in the workspace was inconsistent.

Students discuss how to determine which factor is more influential. If one person's results are consistently higher or lower across all colours, the issue likely lies with their vision. If a person's results are systematically lower for certain colours, it may indicate weaker colour sensitivity in their eyes. Conversely, if all group results are consistently higher or lower, swapping the groups with the most systematic and distinct differences can help, as this may illuminate the problem.

When the visibility numbers are finally assigned to all coloured pieces, it becomes clear that the measure obtained through this process can only be integer values.

Discussion points:

Is it possible to define the procedure with a continuous measure?

Two methods are discussed here.

Wedge Prism Method: One method is to use a wedge-shaped triangular prism made of opaque material, such as white wax. The prism should have a very small apex angle, with one angle measuring 90˚. Student A places a strip of coloured paper parallel to the wedge beneath the thickest part of the prism. Students B and C observe the colour seen through the prism. The prism is slowly moved over the paper towards the edge. The thickness of the prism or the distance from the wedge is considered a measure of visibility.

Milky Water Method: The second method involves using milky water with a few drops of milk or cream. Instead of paper, pieces of coloured plastic are utilised. An elongated aquarium filled with milky water replaces fog. Student A positions the coloured plastic at one end of the aquarium, while students B and C watch from the opposite end. Student A then slowly moves the plastic toward the observers. The distance at which they can identify the colour serves as a measure of visibility.

Students can design their own visibility ranking using these continuous methods and compare it with the layered method.

Finally, once the measuring procedure for visibility is defined, it can be used to assess the visibility of contrasts by altering the background colour, or visibility in darkness by adjusting external illumination. Additionally, the effects of piece sizes, as well as hue, saturation, and lightness, can be examined.

Further explorations:

- How does background colour affect visibility?
- How does illumination affect visibility?
- What is the effect of hue, saturation, lightness, or size of the object?

Social relevance:

- Students reflect that humans (e.g. drivers, pedestrians) are responsible for wearing colours that are visible under various conditions.

KEY LEARNINGS

The task was tested with two groups: one consisting of in-service teachers who are members of the professional learning community in the project, and the other comprising pre-service teachers studying the subject 'Methodology of Teaching Physics' at the University of Ljubljana, Faculty of Education. The brittleness of spaghetti was also tested by one of the in-service teachers from the first group, together with a group of vocational school students.

All reports indicate that participants generally reach consensus on the method quite quickly. However, different groups often arrive at different suggestions, but they happily agree on one when they want to compare their results.

CONCLUSION

This task offers an engaging alternative to the often-dull discussions about measuring standard properties, which students have already learned in past years. All challenges involved in accurately and reliably measuring a non-standard property highlight the importance of a well-defined procedure. Through this process, students realise that developing a measurement method is not as straightforward as it appears for common, everyday measurements. However, the general principles for creating such procedures enable meaningful comparisons between properties lacking standard measurement methods, such as "saucability, " "forcability," and "toothsinkability"- the qualities of pasta called cascatelli, which excel in these aspects (Pashman, 2022).

Co-funded by the Erasmus+ Programme of the European Union

REFERENCES

- Čepič, M. (2023). Units, Density, and Cartesian diver, in this eBook.
- Pashman, D. (2022). Everything you want to know about cascatelli. https://www.sporkful.com/how-to-buy-cascatelli-new-pasta-shape-sporkful-dan-pashman/ (accessed October 2022).

APPENDIX

Measuring procedure

The general measuring procedure is the process where the property of an object or phenomenon is expressed in number and unit. Several conditions must be fulfilled for results to be comparable. The main idea behind the measuring procedure is that all persons who measure obtain the same result if they measure the same property of the same object or phenomenon. Furthermore, the process should be detailed enough that a robot could be programmed to measure instead of a person, and it would have to produce the same result as a human.

To establish a measuring procedure, one must:

a) Define a procedure that can compare the properties of two objects and determine if they are equal or not.

b) Define a procedure that can compare unequal properties of two objects and decide which is "bigger", "larger", "higher", "warmer" or similar than the other. Semiquantitative comparison should be possible. This is not always feasible, for example, the question "Is green more blue than red?" does not make sense.

c) Decide on a standard, which is the property used for comparison, and its unit.

d) Determine how to combine standard objects or phenomena so that the equality of their properties and those of the measured object or phenomenon are comparable.

e) Often, it is easier to measure another property. For example, radar measures the change in frequency and calculates the velocity of a car. This is called measuring transformation. If used, the transformation must not affect the result.

Try to identify procedures from a) to d) or even e) in both example cases.

More about measuring procedures can be found in Čepič (2023).

Co-funded by the Erasmus+ Programme of the European Union