The Cyanometer

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Building a measurement instrument

Building measurement instruments that can provide meaningful results requires special materials and knowledge. Building measurement instruments as a classroom activity can thus be a source of frustration for students.

However, the cyanometer is a notable exception to this rule. The activity requires simple materials: white card, coloured paper in different shades of blue and paint in different shades of light blue. This leaves teachers and students free to focus on the topic of measurement instruments.

Learning by doing

In order for the activity to be beneficial in terms of learning, it is best if the teacher does not reveal too much information right away. The activity will be more effective if the teacher refrains from showing the class pictures of a cyanometer or giving away too many details about the instrument, such as the fact that the different blues are arranged on a scale or that they are numbered. A more effective method is to set up a hands-on learning activity, clearly explaining the objective and giving students the basic materials they will need. Students will then be able to determine on their own the best way to build the instrument as they encounter and solve problems during the activity. This type of activity requires time and thought, trial and error and interaction both with each other and with the teacher.

Introducing the issue of measurement

A good way to begin is by having the class work on prototypes, using small pieces of paper in different shades of blue to be arranged on a piece of white card. This activity will elicit a number of questions.

How should the different pieces of paper be arranged? If the papers are placed in the centre of the card, a cut-out will have to be made next to each one in order to be able to compare them with the sky during measurement. Often, after experimenting with several different positions, several students will put forward the idea of arranging the coloured papers along the edge of the card, which keeps them from having to make cut-outs and which allows the instrument to be used as-is.

How can the measurements taken be recorded for later comparison? An imaginary yet realistic situation is a good way to get students to think about this: 'You and your friends are at different ski resorts and you phone each other every evening to tell each other what you have observed during the day. What do you say?' The answers initially given are usually vague, such as: 'I tell them it's a pretty dark blue...uh...blue'. Students quickly understand that this is not an effective way to communicate measurements. They will then put forward answers like: 'I give them numbers. The blue in the middle is zero. The darker blues are positive and the other ones are negative'. Or: 'I give them letters…sort of like a code'. The discussion continues until a consensus is reached: 'We should all use the same code!' Students will often end up deciding: 'Numbers are still the easiest way to do it!'

There are two steps in building a cyanometer. Left: Carefully-numbered trays of paint in different shades of blue are set out for students to use. Below: The cyanometer is almost finished. One of the last steps is to neatly copy the numbers next to each shade of blue.
Tatiana Ducraux's primary school class, Liotard School, Geneva. Photo: N. Kramar.

Step by step, the students will thus complete the calibration of their measurement instrument themselves. At this point in the activity, the students are generally thrilled to see a picture of the original instrument—because they have had the experience of building one themselves. Classroom research has demonstrated that this type of activity also has a positive effect on students' way of thinking about other measurement instruments. In students' minds, the 'black box' that such instruments ordinarily represent has become more 'transparent'. The choices made in order to build these instruments are more easily understood and the issue of measurement takes on true meaning.

There are two particularly useful examples that illustrate this point. Today's thermometers are calibrated in degrees Celsius (and sometimes in degrees Fahrenheit). However, as recently as the 18th century, scholars used different calibration systems depending on their region or sphere of influence. When sharing measurements with their colleagues, they had to include a table showing the equivalencies between the different measurement systems. The length measurements used today by all scientists come from the metric system created by the French following the French Revolution. Prior to the introduction of the metric system, however, length was measured using different standards, including toises, feet, inches or lines. The fact that the standards varied depending on the country—and even the region—made discussing measurements quite a complicated affair. The continued use of imperial measurements, which remains common in everyday life, resulted in one very nasty surprise for NASA. Due to an error converting distances (and thus approach speeds) from imperial to international measurement units, the U.S. space agency probe crashed on Mars.

Finally, depending on the consensus reached by the class and the teacher's preference, the students could build a cyanometer like the one used in 1787 or the one introduced in 1788. Whatever the case may be, special attention must be given to the fact that the blues of the sky are always lighter than we think, especially in low-lying areas!

Giving students room to invent

Classroom research has shown that students' thought process and the ideas they put forward during this activity reflect the historical developments of the instrument. In fact, inventor Horace-Bénédict de Saussure changed his own cyanometer between 1787 (the model he used at the summit of Mont Blanc had 16 shades of blue numbered from the darkest to the lightest) and 1788 (the one he used at the Col du Géant). In the later version, he no longer painted directly on the card. Rather, he cut out and glued papers painted in advance, which made the instrument easier to reproduce. He also increased the number of shades of blue in order to make the instrument more accurate (the 1787 measurements included shades that were 'between' two readings on the old scale). In addition, he decided to number the shades in reverse order, with the number 1 denoting the lightest blue. However, he never revealed the reasons for this development! Finally, he decided to place the shades of blue on the edge of a round card, which kept him from having to make the cut-out in the centre of the rectangle he had used initially.

Students are both surprised and pleased to learn that a scientist that made pioneering advances in his field used trial-and-error to gradually improve his instrument. This knowledge validates their approach to building the instrument, boosts their confidence in their own ability to invent and keeps their level of motivation high. If the teacher is prepared to give students the room they need to invent and let them build their own prototypes, he or she will avoid revealing too early on in the activity what early cyanometers looked like. These instruments should be used as an indication of the possibilities rather than as a definitive 'right' answer. Of course, this means that the options chosen must be discussed, explored and backed up with relevant arguments. The type of cyanometer built may very well end up looking much like one of the instruments built by Horace-Bénédict de Saussure, but it could also be completely different.

Using the cyanometer

Taking measurements in the field: a 'user guide' for the instrument

The cyanometer in and of itself is relatively simple. Unlike using a 'finished' measurement instrument—a 'black box' in which all options have already been thought out and which is used only passively—students will have to determine a procedure for using their cyanometers; they will have to come up with a 'user guide'. However, the inventor of the cyanometer left us with little information on how to use the instrument. He spoke of observations made 'at solar noon'. He also mentioned 'the zenith', meaning the vertical point in the sky directly above the observer. Therefore, the cyanometer is still a prototype, which creates an opportunity for students. They can enjoy exploring a topic for which few guidelines have been established while naturally moving towards the procedural issues inherent to all types of measurement. However, students will have to be thorough, and this will quickly become obvious to them as soon as the hands-on activity is set up.

Once the students are in the schoolyard with their cyanometers in hand, what should they be looking at? The blue of the sky changes depending on the day and the location—but also depending on the time of day and the direction in which the observer is looking. So, what is the best time of day for taking simultaneous measurements in different locations? What is the best direction in which to point the instrument (north, south, east or west)? What is the best height for observation and how is it determined? These are just some of the questions that students will have to answer. All of these choices depend to a great extent on the objectives set, which the teacher will have to state clearly.

The great French scientist François Arago (1786-1853) made further changes to the cyanometer. His cyanometer looked very different from the one Horace-Bénédict de Saussure built. The scale for measuring shades of blue was hidden inside of a complex device that looked like a telescope sight with a measurable inclination. This led to the belief that Arago included the measurement of the angle of observation inside his instrument. Again, this development was reflected in the idea put forward by some students to build a protractor into their cyanometer! As previously pointed out, it is interesting to note how some of the students' ideas and suggestions follow the historical development of the instrument.

Understanding the situation in which the instrument is used: an introduction to scientific method

Using a cyanometer to take isolated measurements is one thing—the context in which it has been used historically is another. The development of a procedure for using the instrument is where measuring the blue of the sky took on true meaning.

Horace-Bénédict de Saussure built three copies of the 1787 cyanometer. They were meant to be used simultaneously by three people: one at the summit of Mont Blanc, one in Chamonix and one in Geneva. The measurement that the scientist himself took at the summit of Mont Blanc was one of the 25 'observations and experiments' that he conducted there. This measurement was meant to be used in conjunction with other air measurements (pressure, temperature, humidity, carbon dioxide, electrical charge, magnetic attraction, light intensity, air transparency and shadow colour, among others).

This information will introduce to students the need to use isolated measurements in relation to each other. They will then be able to take daily measurements of meteorological data such as temperature, atmospheric pressure and humidity, either using typical instruments or from newspaper weather reports. Using tables and graphs, students may then attempt to identify correlations over periods of a week or longer. For instance, students may notice that humidity tends to rise in relation to temperature but that atmospheric pressure behaves altogether differently. This activity will raise students' awareness—at their level of understanding, of course—that meteorology is a complex science that entails making connections between phenomena of differing scales and that predicting the weather isn't as easy as it appears to be!

Identifying a colour using the naked eye

Direct measurement

Most measurement instruments use indirect measurement via a physical phenomenon appropriate to whatever is being measured. For instance, the thermometer uses the variations in height of a thin column of coloured alcohol that dilates and contracts as the temperature increases and decreases. The barometer uses the variations in volume of a sealed metal chamber that expands and contracts with changes in atmospheric pressure; the mechanism is linked to a pointer that gives the measurement. These two examples involve phenomena that are invisible to the eye and that must therefore be measured indirectly. In fact, what is being measured is an expansion or an increase in volume that correlates with a calibrated scale. Furthermore, to an increasing extent, today's measurement instruments are based on the electronic processing of data collected by sensors; the digital thermometer is an everyday example of this type of instrument.

Teaching the concept of direct measurement using the cyanometer can, as classroom research has shown, offer a broad perspective of the issue. In addition, the concept can be extended much further with students who have prior experience building and using other instruments. The teacher may, however, choose to address the topic with students at multiple levels.

A process that is still used today

Systems designed to identify colours 'with the naked eye' still exist today and are used in a variety of professions. These instruments are similar to the cyanometer, but with different ranges of colours. Yellow scales are used to check the doneness of chips (in restaurants); reds are used to check blood haemoglobin levels (by doctors); and off-whites are used to check tooth colour (by dentists). We learned about these different scales from people who were so excited about the cyanometer that they just had to tell us about the instrument's 'cousins'! The fact that these instruments are used tells us that the human eye is still a powerful tool when it comes to distinguishing colour!

Why measure the blue of the sky?

Although students tend to get very excited about their cyanometers, telling their friends or their parents that they have built an instrument that measures the blue of the sky can seem quite silly. However, there are many reasons for measuring the blue of the sky, and it is useful for the teacher to address the issue in class either during the 'cyanometer unit' or just before wrapping up. Stepping back and gaining a broader perspective on knowledge is always fruitful for students. The historical background of the instrument gives us some useful information concerning this point.

First of all, the residents of Chamonix—the very people who led Horace-Bénédict de Saussure to the summit of Mont Blanc—were terrified of the almost-black blue of the sky at high altitudes. Giving the colour a number and comparing it to other colours—domesticating it—was a way to allay their fears and change their relationship to the world. There are certainly similar examples in more recent history. This viewpoint helps students to 'grow up' and to move from childhood finalism to a more mature vision of the world.

Horace-Bénédict de Saussure believed that the blue of the sky was due to 'opaque vapours' in the air. As these vapours decreased with altitude, he believed that at a very high altitude the sky would be perfectly black and that the stars would shine even during the day. Today we know that the blue of the sky is due to an optical phenomenon: the diffraction of white light by the air in which the red is absorbed and only the blue reaches our eyes. We also know that astronauts see a black sky from space—which means that our 18th century scientist wasn't so far off after all!

Horace-Bénédict de Saussure explored a field which, in his day, had never been studied before. Students at Geneva's Saussure School recently put on a play in which they imagined the scientist in today's world enthusiastically going off to explore the planet Mars—their script couldn't have been more appropriate!

Today, scientists still gather much data on the characteristics of the atmosphere at high altitudes. One interesting idea is to imagine a modern-day ‘cyanometer’. What would it look like? Would it be sent into the atmosphere on board a weather balloon? Would it be equipped with an electric sensor to measure the wavelength of light and linked to Earth by radio waves that send the information to our computers?

Work with the cyanometer: an entry point to scientific method

Other measurable phenomena have proven to be even more valuable in actual use and more operational in the mathematical equations that became essential to science in the 19th century. Horace-Bénédict de Saussure did not draw any particular conclusions from his measurements. He simply wanted to make them available to those who might want to use them in their own research later.

Science often forgets its own history and the long period of development scientific knowledge requires. Science tends only to hold on to ‘final’ results, which students are then expected to learn over a very short period of time. Today’s researchers—even the most brilliant among them—continue to use trial-and-error and to ask new questions. Indeed, this capacity is an integral part of scientific activity. Our hope is that students who build their own cyanometers at school will become aware of the fact that, at their level, they have participated in a truly scientific process—and that they enjoyed it, too! Enjoyment is, after all, one of the objectives of building this instrument. We hope you enjoy the activity!